By Katherine B. Shippen

Illustrated by Charles M. Daugherty

The Bright Design tells the fascinating story of electrical energy and the men who have helped to unfold its secrets. Starting in the twelfth century with Peter Peregrinus whose interest in lodestones led him to manufacture a compass and continuing through to Lise Meitner and Niels Bohr, whose work with nuclear fission made possible the atomic bomb, Miss Shippen has given us a colorful pageant of the men and women from all countries whose curiosity and study not only defined laws and theories but caused enormous changes in the physical and social world around them.

As in *New Found World* and *The Great Heritage*, Katherine Shippen has brought such enthusiasm to her subject matter that not merely the student but also the ordinary reader will be immediately absorbed in *The Bright Design*. The warmth and thoughtfulness of Miss Shippen's work are perfectly complemented by the interesting and detailed line drawings made especially for this book by Charles Daugherty.

Katherine Shippen is descended from an English Puritan family who came to Connecticut in 1639. She is a former history teacher, headmistress and Curator of the Social Studies Division at the Brooklyn Museum. Charles Daugherty is the son of James Daugherty, the well-known illustrator and painter, and is well on the way to a name for himself.

Also by Katherine B. Shippen

NEW FOUND WORLD

THE GREAT HERITAGE

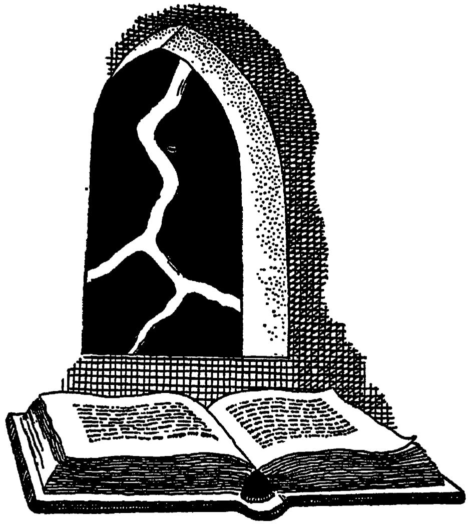
LIGHTFOOT

A BRIDLE FOR PEGASUS

I KNOW A CITY

MEN, MICROSCOPES, AND LIVING THINGS

MEN OF MEDICINE



The Bright Design

KATHERINE B. SHIPPEN

illustrated by

CHARLES MICHAEL DAUGHERTY

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No single thing abides, but all things flow.
Fragment to fragment clings—the things thus grow
Until we know and name them. By degrees
They melt and are no more the things we know.

Globed from the atoms, falling slow or swift
I see the suns, I see the systems lift
Their forms; and even the systems and the suns
Shall go back slowly to the eternal drift.

Thou too, O Earth—thine empires, land and seas—
Least with the stars of all thy galaxies,
Globed from the drift like these, like these thou too
Shalt go. Thou art going, hour by hour like these!

Lucretius, 95–52 B.C.; translated by W. H. Mallock

Once more

for N. and B.

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PART III. HOW THEY STUDIED THE COSMIC FIRE

The Scientists and the Bright Design

From the very beginning of recorded time, there have been strange mysteries in the earth. The lightning tearing its crooked paths down the summer sky; the luminous ribbons of the Northern Lights waving across the polar dark; St. Elmo's fire, playing around the masts of ships at sea—all these were fearful mysteries. Less obvious, but as strange, were the magnet stone that could give "life" to iron, and the yellow amber that attracted feathers and bits of straw when it was rubbed. People noticed these phenomena often: no one could guess there was any connection among them.

The substance of the earth itself was another mystery. What was the earth made of? Were earth and air and water made of fire, as some of the Greeks thought in the early days? Or did they all come from water? Or were they nothing at all but the imagination of men? No one could tell.

And finally there was the mystery of light—a mystery hardly noticed since it seemed so natural to watch day following night, to feel the light of the sun, to see it warming the cherry trees to a drift of white blossoms in the spring, or ripening the grain in the summer fields.

That electricity and magnetism, the atoms made of tiny moving particles, and the moving radiant light, were all one energy, all manifestations of the cosmic fire—this was a truth that men were a long time finding out. For it was much easier

to imagine that these things were supernatural in their essence than that they had a common scientific cause.

Whenever fearful things are little understood they have been said to be the work of spirits. Many thought the magnet stones were "full of gods," and they spoke of the "soul" of the amber. Countless were the legends of how the earth was made: the Hebrews for example thought that it was dust, fashioned by the hand of God. In Persia, in Peru, in China, and in Egypt, and in many other places, the sun was worshipped. Men called it the giver of life, the god who was the glory of all created things.

But there have always been some men who are not content with legend and poetry, those who want to examine and compare, to find out the laws that underlie life and all material things. These men are the scientists. Thales of Miletus was one of the first of them. He lived in Greece in the sixth century before Christ. It was Thales apparently who first tried to study the "magic power" of amber, and who said he thought that water was the "elemental fluid." He was an astronomer also, and watched the skies so long and so carefully that he was at length able to predict an eclipse—an achievement which won him a great reputation. The citizens of Miletus erected a statue to this early scientist. They inscribed it: "Miletus, fairest of Ionian cities, gave birth to Thales, great astronomer, wisest of mortals in all kinds of knowledge."

But the centuries passed, and what Thales had done was half forgotten. In the first century before Christ, Lucretius, the Roman, wrote his long poem *On the Nature of Things.* In it he tried to bring together the scientific facts that had been revealed up to his time. But his poem too was forgotten, and not until the thirteenth century in Europe did Peter Peregrinus

make his studies in magnetism; not until the sixteenth century did William Gilbert add a little to the knowledge of magnetism, and begin to study electricity.

After that, little by little, new knowledge was revealed; slowly its bright design took shape. Among the men and women who studied electricity and the subjects that were associated with it, were rich and poor, old and young, famed and obscure. They carried on their work in Germany and France, Italy and Russia, England and America, and many other places. Each one added only a little to the knowledge that had gone before. Slowly, through patience and hard work, they uncovered many of the secrets of science.

They studied electricity and magnetism, and found them to be related; they found out how to generate electricity and to send it out along wires and through the air. They studied the atoms of which the earth is composed, and learned how to free the tiny electric particles of which they are made. They studied light, and found that the earth's atmosphere is filled with many radiations that the human eye cannot see.

Now, because of the work they did, the life of men around them changed. Not much more than a century ago the streets and houses had been dimly lighted with flickering lamps; now they blazed with electricity. Then the news was carried by word of mouth or letters were sent by slow packets or stage coaches: now it was flashed around the world by radio waves that traveled with the speed of light. Now electricity flashed along copper wires to turn the factory wheels; electric furnaces glared in the big steel plants; and electronic devices opened doors, counted, sorted, matched colors.

Now the electron microscope revealed hitherto unknown

viruses, and X ray treated diseases that had before been baffling. Now pilots of the great airships steered their craft safe to the airports, riding the beam; and there was radar transmission to the moon. Now a great atomic bomb was made with power to destroy a whole city, and men talked of using the power of such a bomb in the new atomic age.

While the world was changing round them, the scientists worked on. They used the new devices their researches had made possible, for these men too were part of the new age. But to create such devices had not been their object. Something in them had made them want to understand the old mysteries that had baffled men so long. They wanted, more than anything else, to explore what Sir Isaac Newton once called "the great ocean of truth."

Some of them had sought to understand the behavior of the magnet and to control electricity; some had sought to understand the material substance of the earth and had released atomic energy; some had sought to understand the nature of light, and had discovered the radiations that quiver through the universe. In the end they found that all three fields were one. For in all three they saw manifestations of the cosmic fire itself.

As they worked—in barren rooms, in universities, in great industrial laboratories—their researches extended further and further, until at length they were sending expeditions to study radiation around the world and up into the stratosphere. And all the inventions and devices at which the men of the new age marveled seemed unimportant to them. For they had traced the cosmic fire until their research had taken them beyond the earth, into the wide empty spaces that lie between the stars.

PART I

How They Studied Electricity and Magnetism

A piece of grayish stone
   with power to magnetize an iron needle;
A bit of yellow amber
   that took on life when it was rubbed.
Scientists in many countries,
   through slowly passing years,
   studying these two.

A crude motor
   made by a whirling copper disk and a horseshoe magnet,
Electricity flashing along copper wires,
Over hills and valleys,
Across plains and mountain ranges,
To light the lights,
And turn the wheels,
And drive the locomotives,
And lift the loads—

The Age of Electricity
Born from the amber
And the grayish stone.

1. The Stone That Is Alive

Once long ago in the hilly pasture lands of Crete, a shepherd made himself a staff and bound its tip with iron so that it would not quickly wear away. And as he walked across a meadow following a herd of sheep, he felt the staff cling unaccountably to the earth. Wondering what the cause of this strange pull to his staff might be, he stopped and dug a hole, and brought up a dark, grayish-looking rock. So the story goes.

Rocks of a similar kind were found in many places in Greece. There were large deposits of them in Thessaly, particularly in a place called Magnesia. People called them lodestones, or

magnet stones. No one knew what the strange stones were, nor whence they had this power of attracting iron. Thales, the Greek, said, "All things are full of gods. The magnet is alive; for it has the power of moving iron."

Century after century people speculated about the strange power of these stones that were full of gods. Socrates said that such a stone "not only attracts iron rings, but also imparts to them a similar power of attracting other rings; and sometimes you may see a number of pieces of iron and rings suspended from one another so as to form quite a long chain." The workers of the iron mines of Samothrace in Greece made such a chain.

As time passed, many fables and tales grew up about the lodestone. So you may read of a temple whose dome was built entirely of iron that had been magnetized. A statue of a beautiful woman hung in mid-air there, held aloft by the iron's strange power. And it was said that there were mountains in the north "of such great powers of attraction that ships are built with wooden pegs, lest the iron nails should be drawn from their timber."

Over and over, people speculated about why the lodestone behaved as it did, but no one tried to find out the reason by experiment. The age of scientific experiment had not yet come.

There was one man who lived in the early thirteenth century who did experiment with magnets. He tried now one thing and now another, making notes of what he found, thinking about magnets constantly. His name was Peter Peregrinus of Maricourt, and he was a pupil of Roger Bacon. Roger Bacon said, "What others strive to see dimly and blindly, like bats in the twilight, he gazes at in the full light of day, because he is a master of experiment. . . ."

Peter Peregrinus wrote in a letter to a friend what he had found out about magnets. The letter was written from a camp at Lucera which was besieged by Charles of Anjou in 1269. In this letter he described how he had made a little globe of magnet stone which he called a *terrella,* marked lines on it, and experimented to see what direction an iron needle took on it. He found that the needle pointed toward definite points at north and south, and called these places the "poles." The poles were therefore the regions where magnetic power seemed to concentrate. They were not always at the exact northern and southern extremities of the globe: he had found out that the magnetic north is not the true north.

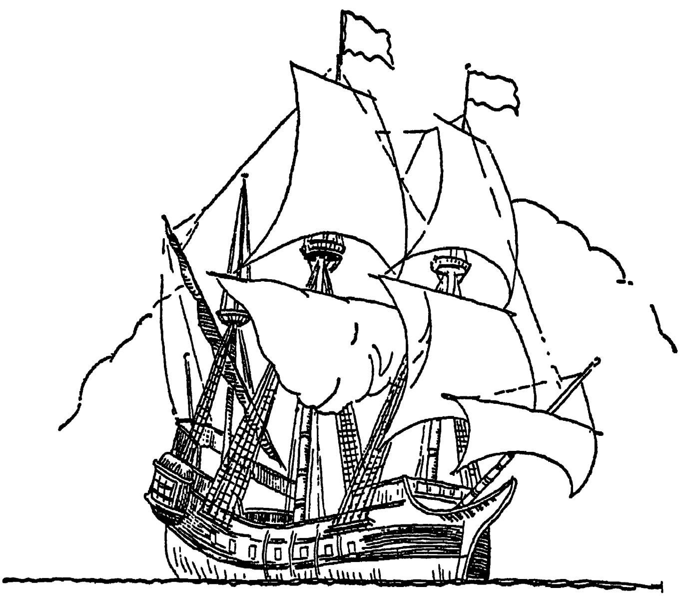
In his letter Peter Peregrinus tells further how he placed a lodestone in a wooden skiff which was floated on water, and "if this pole then turned away a thousand times, a thousand times it would return to the same place, by the will of God." He noticed too that broken fragments of magnets behaved exactly as did the magnets themselves. And he knew how to construct a pivoted compass as well as a floating compass.

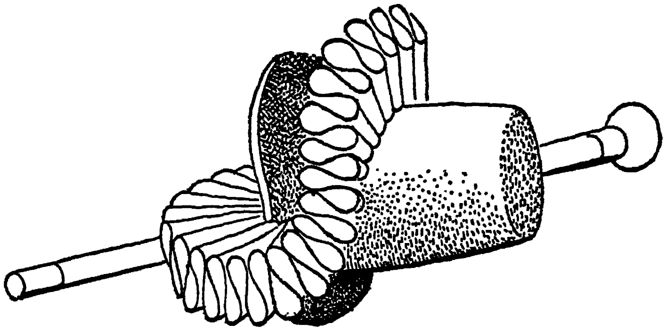
Peter Peregrinus was not the first man to make a compass. It may have been the Chinese who first steered their vessels with the aid of a magnetic needle; or it may perhaps have been the Italians (the sailors of Amalfi on the Gulf of Salerno took great pride in claiming as much); or it may have been the Arabs. Compasses were probably used before ever Peter Peregrinus was born. But though he certainly did not make them first, he was the first man to study their behavior—wondering why the needle rubbed against the lodestone turns toward the north, wondering whether the piece of magnet stone which

he fashioned into a sphere was not like the sphere of the earth itself.

But who knows anything about this Peter Peregrinus? The most diligent searcher cannot find out anything about him. There is not even a picture to show what he looked like.

So time passed, and Peter Peregrinus was forgotten. And no one tried to understand the power of the magnet, though many vessels followed the guiding of their compasses across distant seas. So it went for over three hundred years. Then William Gilbert of Colchester began to make some experiments.





2. Vis Electrica

William Gilbert of Colchester was court physician to Queen Elizabeth of England. And before he received this appointment the records say that "he had already practised with great success and applause." He was born at Colchester, the son of the Recorder there. After his education at Cambridge, where he had received the M.D. degree in 1569, he traveled on the Continent, and then went to London to practice medicine, taking a house on St. Peter's Hill, near St. Paul's Cathedral.

Not many of his remedies have been preserved, but it is known that he treated one patient for "spots in the eye" by telling him to take worms in a little wine or water—"the worms with many feet that are found between the trunk and bark of trees." The dose was to be accompanied by a repetition of the Lord's Prayer. He should not of course be blamed for such advice: remedies of this sort were in common use in his day.

Gilbert's reputation as a doctor was very great, and brought him much favor from the Queen. Soon he gave up his house on St. Peter's Hill and went to live at the Court. The stipend for his services as court physician was £100 a year in addition to his living.

Gilbert's work as physician to the Queen was certainly not very difficult or time-consuming: he had plenty of time to follow his own bent. Therefore he was in the habit of inviting his friends, who were the greatest scholars of the day, to come to Court, bringing their books with them as well as their globes and maps, in order that they might discuss various difficult and puzzling questions. They liked to think of themselves as philosophers, or true lovers of learning, and theirs was in fact the first scientific society, so far as we know. They prided themselves that all the new ideas of the age were brought to the Court of the Queen.

Sometimes, according to tradition, Queen Elizabeth herself sat among them, to hear the great men talk. A painting, made at a later date, shows how the light streamed in at a leaded window upon the Queen in her satin and pearls, with emeralds gleaming. Around her the great scientists are seated, and before them all stands William Gilbert, with a lodestone in his hand.

For though no one had made experiments with lodestones for over three hundred years, so far as we know, William Gilbert, like Peter Peregrinus before him, found in the ugly gray stone and its magnetic powers a kind of fascination, a puzzle which he spent nearly a whole lifetime trying to solve.

He must have scorned the notions of magic which had surrounded the lodestone so long. In Gilbert's time the lodestone was commonly "accused of producing melancholy, of making

love philtres, of losing its power when rubbed with garlic, and regaining it when smeared with goat's blood, of declining to attract iron in the presence of a diamond. . . ." All this was nonsense, Gilbert must have thought.

One imagines him rubbing a needle on the stone's rough surface, holding it near a mass of iron filings, watching as the iron filings seemed to leap toward it.

"See, Your Majesty," he must have said. And Elizabeth, with fleets and armies at her command, marveled at the power of an inert iron needle.

It is not known whether William Gilbert of Colchester ever read Peter Peregrinus' letter. Probably he did not. But he followed Peter's method of experimenting: that is why he found out so much.

He found out first of all that he could not magnetize all substances; only certain ones seem to take life from the stone. An Italian, Giambattista della Porta, had said that iron rubbed with diamonds would become a magnet, but Gilbert said, "We made the experiment ourselves with seventy-five diamonds in the presence of many witnesses, employing a number of iron bars and pieces of wire, manipulating them with the greatest care while they floated on water, but never was it granted to me to see the effect claimed by Porta."

Like Peter Peregrinus, Gilbert made a little "terrella" of lodestone, and observed in how many ways it was like the earth itself. He wrote, "Toward it, as we see in the case of the earth, magnetic bodies tend from all sides, and adhere to it. . . ."

And again he wrote, "Like the earth it has an equator . . . it has the power of direction and of standing still at north and south. . . ."

There were many things about his little terrella which he could not understand—but then the cause of the earth's magnetism and its changes are matters which we cannot understand completely even to this day.

As time passed, William Gilbert collected in a book all that he had been able to find out about magnets. Its title was *De magnete, magneticisque corporibus, et de magno magnete tellure; physiologia nova.* And this means: "Of the magnet and magnetic bodies, and of that great magnet the earth; a new physiology."

Magnetism was, however, only one of the matters that were of such absorbing interest to William Gilbert. He was equally interested in studying the power that he could give a bit of yellow amber when he rubbed it with a piece of fur.

"It has a *vis electrica,*" he said to his friends. "A life of its own that is electric." It was the first time that anyone had used the word "electric." He took it from the Greek word *elektron,* meaning amber—Gilbert was a good Greek scholar like all the gentlemen of his day.

Here indeed was another mystery, this yellow amber which, when he rubbed it with fur, drew bits of feathers and straws to it as if it were alive.

"But I have found in my experiments that it is not only amber that is electric. Jet seems to behave in the same way, and sulphur. Some objects are electric, some nonelectric: I have made a list of the various substances which seem to contain the *vis electrica.* Observe when I rub them—"

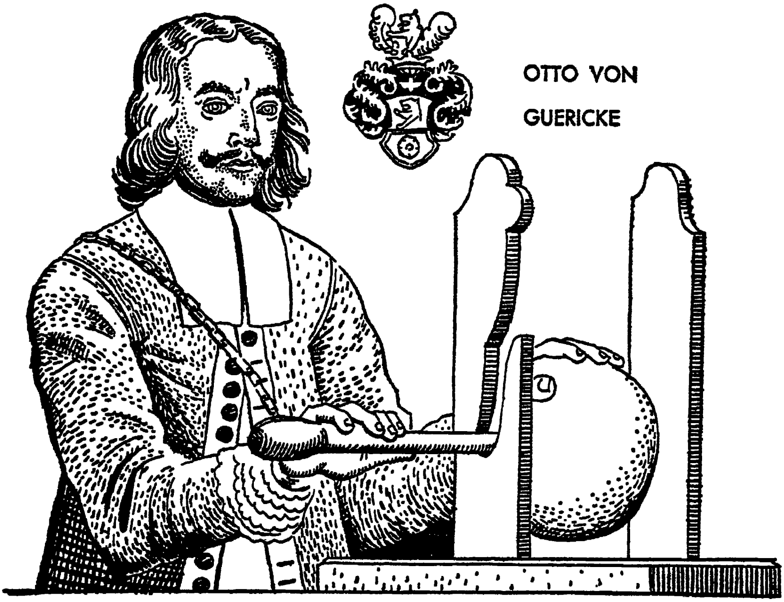
Magnetism and electricity—mysteries both, which William Gilbert could not understand. Many men after his time were to spend their lives in trying to solve the riddle of what they

were. And it was not until nearly two hundred years after Gilbert's time that a French scientist, André Ampère, was to prove that there was any connection between them.

As he made his experiments, Gilbert's reputation spread beyond the Queen's court, beyond England even. In Italy the great Galileo wrote, "I extremely admire and envy the author of *De magnete.*" And Thomas Fuller in his *History of the Worthies of England* said that Gilbert's mind had "the clearness of Venice glass, without the brittleness thereof."

But William Gilbert, whose mind had the "clearness of Venice glass," set aside his ruff and his tall crowned hat, and took to his bed at last. And he died in 1603, the same year that his sovereign Queen Elizabeth died. He was buried in the chancel of Holy Trinity Church in his native town of Colchester.

It was so long ago that we do not know much about his dying. Did he die regretfully, wishing that he could have more time to go on with the experiments in magnetism and electricity which he had started? He need not have done so, for there were others now who could carry on the experimenting where he had laid it down.



3. *A Sphere of Sulphur*

Everyone seemed to be experimenting with electric attractions in the years that followed Gilbert's death. For what could be stranger or more amusing than a piece of inanimate stuff that suddenly seems alive?

Robert Boyle, who was an Irish gallant as well as a scientist, noticed "that false locks of hair, brought to a certain degree of dryness, will be attracted by the flesh of some persons. I had proof in two beautiful ladies," he said, "who wore them; for at some times, I observed that they could not keep them from flying to their cheeks, and from sticking there, though neither of them had occasion for or did use paints."

What jokes and delicate compliments, what laughter and blushing, must have accompanied Boyle's experiments.

"One of the ladies," he said, "gave me leave to satisfy myself farther; and desiring her to hold her warm hand at a convenient distance from one of those locks taken off and placed in the free air, as soon as she did this, the lower end of the lock which was free, applied itself presently to her hand."

But it was not only in the drawing rooms that electric attractions were noticed. A group of the most eminent scientists in London sat spellbound while Sir Isaac Newton rubbed a round piece of glass and made some small bits of paper dance with it.

"Rubbing a pretty while the glass briskly with some rough and raking stuff, till some very thin paper, laid on the table under the glass began to be attracted and move nimbly to and fro . . . leaping up to the glass and resting there awhile, then leaping down and resting there; then leaping up and perhaps down and up again."

It took a prodigious lot of rubbing, to be sure, to produce this mysterious force. Here and there people wondered whether they could make more of it. You could not really do much when there was so little to experiment with.

That was the opinion at least of Otto von Guericke of Magdeburg in Germany. He must have hated fussing with small inefficient things. He hated talking and guessing. He once said, "Oratory, eloquence in words, or skill in disputation avails nothing in the field of science." If there was need of a way of making more electricity, then he would not talk about it: he would find the way.

Otto von Guericke belonged to an old family in Magdeburg, and a highly respected one. He had gone to study law

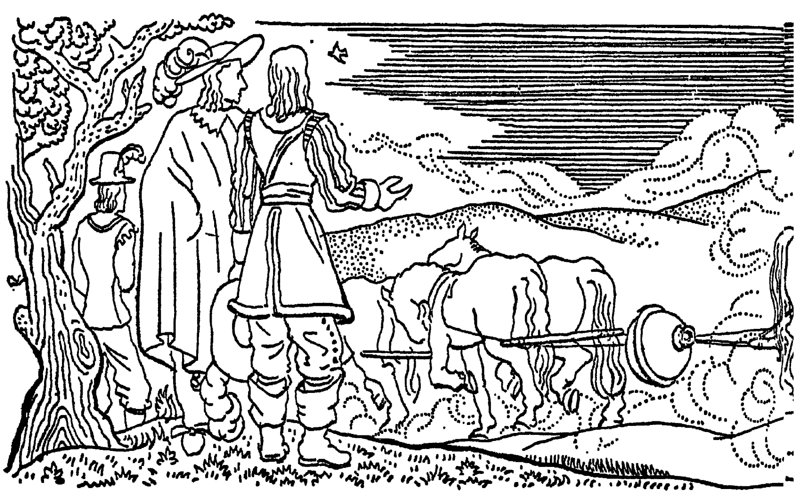
in Berlin and in Leyden, and later, like most of the young men of his day, he had traveled in England and France and Italy. It was in talking with scientists in those countries that he first became interested in electricity. He wanted to study it, to experiment with it, to produce it in larger quantities. All his training and all his desires seemed to point toward the study of this new scientific mystery.

But it has often happened that men with great scientific insight and great gifts for experimentation have had to put aside these interests in order that they might turn to more pressing things. And this was true of Otto von Guericke. Fascinated though he may have been by the strange power of electricity, he paid no heed to it for many years. For he was a citizen of Magdeburg, and Magdeburg, "that great and splendid city that stood like a fair princess in the land," needed his help. It was the time of the Thirty Years' War between the Catholics and Protestants, and Count von Tilly with his Catholic forces laid siege to the city. In spite of the resistance of the sturdy burghers, the fortifications were finally battered down and there was fighting in the streets. Von Guericke fought with the best of Magdeburg's citizens. When the city was finally taken he escaped and joined the army of Gustavus Adolphus of Sweden.

When the Thirty Years' War was finally over, von Guericke returned and helped to rebuild the city where houses, churches, and bridges, and even the Rathaus itself, had been destroyed. So active and able did he prove himself that the citizens finally elected him burgomeister, and he continued to hold this post for more than sixteen years. But the mind of the busy and important Burgomeister of Magdeburg must often have turned back to the mystery of the electric charges that fascinated him

so much. And somehow he found more and more time to devote to his experiments. At first he worked with barometers and thermometers, then he began to try to create a vacuum, and finally he returned to his old desire—to experiment with electricity.

It must be conceded that the good citizens of Magdeburg did not understand very much about what he was doing; in fact, they regarded his experiments with a good deal of misgiving. When the Burgomeister made a giant barometer, concealing the tube inside his four-story house, and arranging it so that a little man rose to his roof when the day was fair and descended into the house when it was stormy, they whispered something about the wickedness of trying to confine the spirits of the weather in tubes and bottles. When he made a great thermometer twenty feet high, up and down which the figure of an angel moved, pointing to the temperature, they thought it blasphemous. No doubt von Guericke, who was as good at



showmanship as he was at scientific experimentation, enjoyed all this to the full.

They thought very little of his efforts to prove that it was possible to pump all the air out of a sphere and so create a vacuum. He had tried this first with a wine cask, but it collapsed "suddenly with a loud clap and to the terror of all." So he joined two hollow hemispheres of copper, and when he had pumped the air out of them it took sixteen horses, four teams hitched to each side, to pull the hemispheres apart.

Not only his neighbors, but many wise men of his time, were critical of von Guericke for trying to perform this experiment. It was well known that Aristotle had said, "Nature abhors a vacuum." It appeared wholly wrong to question any statement that Aristotle had made; and most people thought the thing was quite impossible anyway. Dr. August Hauptman, a learned man of Leipzig, wrote, "It would not be possible to either angel or devil to create a vacuum."

Nevertheless von Guericke had made his hollow copper hemispheres, and the news of them soon spread abroad. It was in fact not long before he was invited to Regensburg, and the Emperor Ferdinand III and the whole Reichstag sat fascinated while the sixteen horses strained and pulled in the effort to separate the halves of the great copper ball. Robert Boyle in England, hearing of the great experiment, tried making an air pump that would create a vacuum himself. He even made improvements in the air pump, so that some people began to speak of it as Boyle's invention. But it was von Guericke who had first done the extraordinary thing: von Guericke who had first dared to say that a vacuum might be possible; that even the great Aristotle might be wrong.

The barometer with its manikin, the thermometer with its angel, the copper hemispheres that it took sixteen horses to pull apart—these were not von Guericke's only scientific interests. For Galileo had first looked at Saturn through a telescope in January 1610 when von Guericke was a boy of eight. Many others worked at grinding lenses after that, and pointed their long tubes toward the sky. In von Guericke's time it was still dangerous to make astronomical discoveries, for more than one scientist had been tortured by order of the Inquisition for such researches. However, von Guericke was not a man to be frightened by such reports as this. He too began to spend long nights watching the movements of the stars through a telescope, and was the first to prove that comets occur periodically. He wrote a long book on his theory of the universe in the Latin that was the scholar's language of his day. But it is not these theories and experiments that concern us here.

It was von Guericke who first succeeded in making electricity in appreciable quantities, and who made a number of original observations about it. Just as the rumors of his other experiments had caused gossip and suspicion among his neighbors, so they began to talk about him now. What was it he was doing, anyway? The rumors spread even into France. The French Lieutenant of Police, Monconys, traveled all the way from Lyons in 1665 to witness for himself the strange goings on. He wrote a report of what he had seen in von Guericke's house in a book called *Voyages*, and told of how he had seen von Guericke with a ball "made of nine minerals," pursuing a feather around the room, preventing it from falling to the ground although he did not touch it.

Of course the ball was not made of "nine minerals" at all. It was made of sulphur. Otto von Guericke has told, himself, how he made it. "Take a sphere of glass called a vial," he writes. "Put in it sulphur that has been pulverized in a mortar, and liquefy by placing it near a fire. When this has become cool, break the [glass] sphere, take out the globe, and keep it in a dry place."

This sphere of sulphur "as big as an infant's head" was to be his electric machine. He bored a hole through it, inserted an iron rod as an axis, attached a handle to grind it round and round. Now, holding the palm of his hand against the sulphur, he ground the crank. The sphere became electrified. Bits of paper, feathers, and tin foil that he had placed beneath it leaped up and clung to it as it moved round and round. The sulphur sphere was filled with the electricity.

Moreover he found that this electricity could be transferred to other objects. He could electrify another ball of sulphur and

with it influence the movement of a feather—the feat that had so astonished Monconys.

With much experimentation and keen observation now, von Guericke noticed that electricity could be transferred from his ball to another body by conduction. He wrote, "The sulphur globe having been previously excited by rubbing, can exercise likewise through a linen thread an ell or more in length, and there attract something else."

He noticed too that "If you take a globe with you into a dark room and rub it, especially at night, light will result!" A faint, faint light it must have been, that first man-made electric light.

And he noticed, as Benjamin Franklin was to see later, that the feather which he drove about the room with his charged globe "approaches the points of any object whatever before it, and it is possible to bring it where it may cling to the nose of the spectator."

Great discoveries these—enough to absorb a man completely. What did it matter if his neighbors regarded him with more and more suspicion? He had not time to explain to them what he had found—perhaps they would not have understood if he had. But he wrote down all his findings carefully for the learned of his own and of later generations to read.

Did he take these records with him when he finally had to leave his house because an influenza epidemic was decimating Magdeburg? He could not fight off the epidemic as he had once tried to fight off Tilly's troops. For he was an old man now, and quite feeble. He packed what he needed to take with him, and made his way to Hamburg where his son lived. He died there on May 11, 1686: he was eighty-four years old. And it is strange

somehow that only in very recent times did anyone even begin to appreciate the things that he had done.

No one knows exactly what happened to the friction machine that he had made. It was probably considered not worth keeping, although many a museum would like to have it now. But the idea of a machine to generate electricity had been born. Here and there in scientific circles, after his time, people began trying to make better machines. They made them of glass instead of sulphur, and tried putting little pads of leather or of cat's fur on them instead of using the palm of the hand to produce friction.

And, having perhaps grown tired of simply watching straws and bits of paper dance about, they tried new experiments with the electricity they generated. One of the first to try making a new electrical experiment was a Frenchman, Charles François de Cisternay Du Fay.

4. *Sparks in the Dark*

Charles François de Cisternay Du Fay seems like a man who was born to sparkle. Whatever he did, and wherever he went, there was a sparkling quality in him.

At first he was a soldier—a soldier in the army of Louis XIV. There were the bright uniforms for him, the rolling drums, the bugles, the glorious fights on far-off battlefields. History does not say why he abandoned the military life. Did he find that there was blood and dust on the battlefields as well as glory?

Whatever it was, he soon had another calling, for Louis XIV made him head of the great gardens at Versailles. Here, in a

place that had once been a sandy waste, he planted rare and beautiful trees of many species, bordered green lawns with neat clipped hedges, set up white statues in the leafy shadows, and set the myriad fountains splashing and glittering in the sun. Here, too, he arranged for fetes and festivals, for torch-lighted processions on the wide staircases, and dancing on the terraces to the sound of soft string music. But this too was only for a time. New pursuits called to him, new ways of serving *Le Roi Soleil.*

Louis not only boasted of his victorious armies and his splendid palaces and gardens, but was also proud of the men of learning and art who lived at his Court. There were musicians, artists, and poets without number who owed their living to his bounty. And scientists also were generously supported.

So now Du Fay was a member of the *Académie des Sciences,* which the French king had founded in 1666, and he received a generous pension from Louis. He gave up his military career and resigned his brilliant appointment as head of the gardens at Versailles, determined to become a philosopher, as men of science called themselves then. He decided that he would investigate that sparkling stuff men called electricity. Everyone in France seemed to be talking about electricity, though no one seemed to know much about it, or what could be done with it. If Du Fay could make new discoveries in electricity, what new brilliance he would add to the King's renown!

He knew probably of the work that William Gilbert had done with the *vis electrica*—how he had rubbed amber, and rubbed glass, and classified all things as electric and nonelectric. He probably knew also of von Guericke's friction machine and

how he had conducted electricity from one substance to another. He went on with his work from there. He rubbed silk and fur and cloth, he rubbed amber, sulphur, glass, and metal. His workshop was cluttered with samples of this and samples of that. He had all kinds of friction machines, and young apprentices rubbing away without machines.

Soon it seemed to him that there were two kinds of electricity. The electricity he made when he rubbed a bit of amber with a piece of fur was different from the kind he made when he rubbed glass with a piece of silk. He called the one resinous, because amber is made of resin, and he called the other vitreous —it gave a certain dignity to use a Latin name for glass. He noticed that objects charged with resinous electricity stuck together, attracted one another. The same thing was true of objects charged with vitreous electricity. But an object charged with resinous electricity had no attraction for an object charged with vitreous electricity. He thought and thought about why this should be true. Finally, being a man of imagination, as all good scientists should be, he made an hypothesis. He said, electricity is an invisible fluid, or rather two fluids. All solid bodies are impregnated with them. When the two fluids are together in a substance they neutralize each other, but when you rub the substance, one or the other of the fluids is released.

Later scientists were to prove Du Fay's conjecture partly wrong. But, after all, it was the only explanation he could think of. And to his credit it must be said that he was the first to discover that there are two kinds of electricity.

So Du Fay worked on at Versailles, more and more fascinated with his electric fluids. William Gilbert had thought that some bodies were nonelectric, that it was impossible to produce

electricity in them. But it seemed to Du Fay, experimenting, that there must be very few of these. In fact, he finally believed that all things were electric—that there was electricity in everything.

Some things, like metals, took it on much more easily; others, like silk and wax, were more difficult to electrify. He found too that the electricity could be led to some things easily, and to others less easily. He coined the words "conductor" and "non-conductor."

Everything in the world, though, held the electric fluid, Du Fay thought: not the objects in his workshop only, but the trees and the stones and the earth itself—and the white marble cupids under the leafy boughs in the great Versailles gardens. Through all the things in the world, he thought, the electric fluids passed.

And if the whole world was impregnated with the electric fluids, then Du Fay himself, being a part of the world, must also be capable of having the electric fluids pass through him. One can see him looking down at his own wrists with the lace ruffles falling over them, at his own legs in their silken hose. When a man stood on the ground the electric fluid must pass through him down into the earth. But if he was raised up off the ground —by some cords, for instance, through which it was hard for the electricity to pass—would the electricity accumulate in him? What would happen then?

News traveled slowly in those days, even to the Court of Louis XIV, but news had come from England that some scientists there had tried to electrify a little boy. Du Fay must have pondered on this news, looking down at his own delicate wrists, at his slender legs. He was a man who loved the dramatic. . . .

It is not hard to reconstruct the setting of Du Fay's experiment, although the actual details of it have been lost. He must have thought that the thing should be done in secret, since he would not risk his reputation. Yet he could not do it altogether alone. Abbé Nollet was trustworthy and discreet; he could be trusted to help.

To a lonely cottage at the edge of a park they brought a friction machine. They also brought some strong ropes made of silk. Carefully Abbé Nollet fastened the silk ropes to a rafter, slipped them under Du Fay's armpits, and raised him from the ground. Then he began to grind the crank of the friction machine, and Du Fay touched the moving globe of glass.

"Do you feel anything?" Abbé Nollet kept asking.

But Du Fay felt nothing. Would his body not conduct the electric fluid after all?

Abbé Nollet paused. He leaned over and touched Du Fay's body with his hand. He felt the smart crackle of an electric shock.

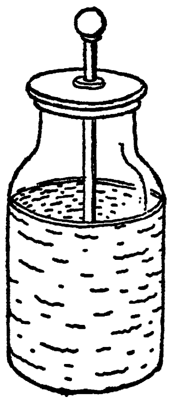
So it had worked after all. Day after day they went to the little cottage; Du Fay was hoisted up on the silken ropes; his body was filled with electricity. Once, when the Abbé Nollet had ground for a very long time, Du Fay's hair seemed to stand up on top of his head, or Abbé Nollet thought so.

Once it was late when they reached the cottage. It was already dark by the time the friction machine was in order and Abbé Nollet was ready to begin his grinding. But they decided to go on with the experiment in the dark.

Then when Du Fay had been hoisted to his rafters, and the Abbé Nollet had ground his wheel round and round, suddenly, to their great excitement, sparks went shooting out of Du Fay's

body through the dark. Abbé Nollet said afterward that he would never forget his surprise. Du Fay was exhilarated. This was an exhilaration beyond anything Charles François de Cisternay Du Fay had ever experienced. It was finer than leading an army into battle, finer than organizing the most beautiful of fetes in the beautiful gardens at Versailles: to hang from a rafter by silken cords, and to know that the electric fluid had flowed into him, as it flowed in greater or lesser extent into everything else in the world.

Charles François de Cisternay Du Fay had held the electricity in his own body as if it had been water in a jar. Would it actually be possible to hold electricity in a jar?



5. *Electricity in Bottles*

By the middle of the eighteenth century, experiments with electricity were so popular that public exhibitions were given in Germany and Holland, and people crowded the halls to see what marvels could be performed with electric friction machines. And in many workrooms patient experimenters were trying to understand the behavior of this strange force.

Since Du Fay's announcement that some things were good conductors and some not, many people became interested in trying to lead electricity from one thing to another. That is what Ewald Georg von Kleist, the Dean of the Cathedral in Camin in Pomerania, was doing. Interest in electricity had invaded even the monasteries by the middle of the eighteenth century, and many monks were making experiments. It was in 1745, to be exact, that von Kleist carefully lined and wrapped a bottle with silver foil. He charged the inner coat of silver foil

heavily with his friction machine. He held the wire so that it made a connection between the inner coat and the outer one over the top of the bottle. He felt a shock run into his arm and chest. It was a shock so strong it made him stagger.

It is curious that in the very next year, that is, in 1746, a renowned scientist of Leyden, in Holland, tried very much the same experiment. His name was Pieter van Musschenbroek. He charged a bottle in the same way. Then one of his friends held the bottle in one hand and with the other started to unfasten the wire that connected it with the friction machine. He too felt the staggering shock as the electricity was discharged.

The scientist van Musschenbroek was greatly interested. He tried the experiment again, but this time he tried it on himself. The result was exactly the same, and he wrote to a fellow scientist soon after that he "would not take another shock for the kingdom of France."

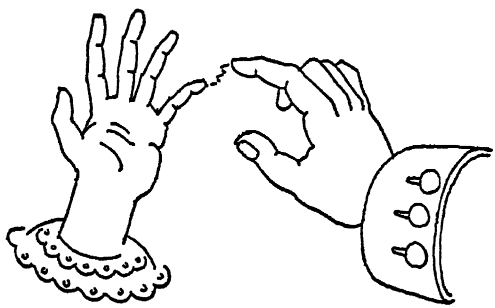
So the discovery had been made: electricity could be stored in a bottle or jar, and carried around, and discharged at will. Soon people were making these jars of electricity everywhere. They called them Leyden Jars, because Pieter van Musschenbroek had made one in Leyden and Pieter van Musschenbroek was an eminent scientist. Of course the pious Dean von Kleist had made one in Pomerania first, but he was not such a well-known scientist, and that perhaps was why the Leyden Jar was not called a Pomeranian Jar.

In France, Abbé Nollet, who had helped Du Fay with his great experiment, made himself a Leyden Jar, and brought it before the King to demonstrate its power. The King's Guard, a hundred and eighty in number, lined themselves up in full

regalia before the throne, and the shock was passed from man to man, to the great wonder of them all.

Not long after this in Paris, at a Carthusian monastery, the monks lined themselves up in the courtyard, touching hand to hand. Then when the Leyden Jar was discharged, the shock sent them all jumping into the air together.

Soon news of the Leyden Jars and the shocks that they could give seemed to have spread everywhere, and mountebanks



were traveling from one hamlet to another giving demonstrations with their Leyden Jars. It was much more exciting to feel a shock from the innocent-looking bottle than to watch a juggler or a trained bear.

But it was not only at the roadside shows and the inn courtyards that people thrilled to the strange shock of the Leyden Jars. In the great halls of the rich and titled, where the candlelight gleamed down on silken coats and billowing ruffles, when the music of flutes and violins was quiet, and the company had grown tired of dancing, someone would bring out a Leyden Jar, and the gentlemen and ladies would try giving one another

gentle shocks. This was a very new and fashionable entertainment indeed.

So in the eighteenth century, rich and poor, learned and ignorant, pious and fraudulent—each in his own way was enjoying the new sensation. To some it seemed that there ought to be some useful purpose to which this electricity could be put, yet it was hard to tell what this might be. They could not yet imagine lights and motors, refrigerators and kitchen ranges, dependent on electricity for their power. Since they wanted to use electricity somehow, they tried curing illness with it. Bloodletting, poultices, and medicines made with herbs had long been tried, with but indifferent success. Perhaps this new electricity might do better, they thought. So patients suffering from mysterious and painful maladies came to the doctor's office, and he gave them a shock of electricity from his Leyden Jar, and they thought that perhaps they felt better. And perhaps they did.

Soon the bottles of electricity were known to all sorts of people in all the corners of Europe, and before long news of them had crossed the Atlantic to America. Benjamin Franklin, who loved new things, heard about them. First he bought a friction machine, and then before long he was experimenting with Leyden Jars too.

6. The Keys on the Kite String

"In 1746, being at Boston," Benjamin Franklin once wrote, "I met there a Dr. Spence, who was lately arrived from Scotland and showed me some electrical experiments. They were imperfectly performed, as he was not very expert; but, being on a subject quite new to me, they equally surprised and pleased me."

So pleased indeed was Franklin with the "electrical machine" that he asked to buy it, and had it sent to him in Philadelphia.

Benjamin Franklin was forty years old that year, and he lived in a comfortable house on Market Street. He had done well in his printing business, had founded a flourishing publishing concern and started various other enterprises. But although he was a good business man, he was not so concerned in the life

of trade that he could not spend some energy on philanthropic and scientific matters. His new purchase was more than a mere plaything—he did not know of what practical value it might be, but he intended to see what he could learn about electricity with it.

The "electrical machine" Franklin had bought was similar to the one von Guericke had made, but instead of being a ball of sulphur it was a tube of glass. By rotating it with a handle and holding your other hand against it, you could generate enough electricity by friction to make a smart crackle and even to send out a spark. If the person so charged with electricity touched another person, the electricity was passed on to him.

Franklin was fascinated with his new purchase and with trying to work out the solution to the questions it presented. What exactly was this "electric fluid?" How did it behave when it was hot, or cold, or dry, or wet?

"I never was before engaged in any study that so totally engrossed my attention and time as this has lately," he wrote an English friend.

So after the machine arrived, he invited his friends to his house on Market Street to see it. They came back day after day: the house was crowded with them. He wrote, "My house was continually full, for some time with people who came to see these new wonders. To divide a little this encumbrance among my friends, I caused a number of similar tubes to be blown at our glass house, with which they furnished themselves, so that we had at length several performers."

Soon they were all experimenting and taking notes on what they observed. Franklin carefully wrote down their observations in his notebook. Due credit was to be given to every man

for his discovery, whatever it might be. They formed the first scientific society in America.

Franklin himself worked harder than any of them at his experiments. His laboratory was his house. His equipment were such things as a vinegar cruet, a salt cellar, a pump handle, and "a little machine I had roughly made for myself."

To Benjamin Franklin and his friends the Leyden Jar and the electricity that could be stored in it were phenomena to be particularly observed and studied and thought upon.

By 1747 Franklin was able to write to his English friend, "We have observed some particular phenomena that we look upon to be new."

He had decided that the two electric fluids, vitreous and resinous, which Du Fay had talked of, were in fact the same thing. He wrote that "electric fire" is a "common element" existing in all bodies. If a body acquired more than its normal share of it, he called the charge "plus," and if less he called it "minus." The "plus" was positive electricity, the "minus" negative. These terms have been used in electricity ever since.

The year 1748 wore on, and Franklin, who had retired from business, became even more engrossed in his study of electricity. He wrote that he was "chagrinned" because his studies had produced nothing useful for men. He decided that he would end the season's work at any rate with a party. It was to be a kind of electrical party—a "party of pleasure on the banks of the Schuylkill. Spirits at the same time are to be fired by a spark sent from side to side through the river without any other conductor than the water: an experiment which we some time since performed, to the amazement of many. A turkey is to be killed for our dinner by an electrical shock, and roasted by the

electrical jack, before a fire kindled by the electrified bottle; when the healths of all the famous electricians in England, Holland, France and Germany are to be drank in electrified bumpers, under the discharge of guns from the electrical bottle."

Time passed, and Franklin's more serious experiments continued. His little notebook must have been packed with the items which he carefully jotted down. In November 1749 he was considering the properties of lightning, and comparing it with electricity.

"Electrical fluid agrees with lightning in these particulars," he wrote: "1. giving light 2. colour of the light 3. crooked direction 4. swift motion 5. being conducted by metals 6. crack or noise in exploding 7. subsisting in water or ice 8. rending bodies it passes through 9. destroying animals 10. melting metals 11. firing inflammable substances 12. sulphureous smell."

And he continued, "The electric fluid is attracted by points. We do not know whether this property is in lightning. But since they agree in all particulars wherein we can already compare them, is it not probable that they agree in this? Let the experiment be made."

Let the experiment be made indeed. But how was it best to make it? How draw the lightning from the sky, so that it might be examined by men? If lightning was electricity, and if it was generated in the clouds, could it be drawn down by a metal conductor similar to the points and stored in a bottle as you would lead the electricity from a friction machine and store it in a Leyden Jar? Undoubtedly metal was the best conductor, though not the only one. If that was not possible, could the dangerous lightning at least be drawn down into the earth, and so made harmless?

Franklin wrote a careful paper on the likenesses between electricity and lightning, and sent it to London to be read by the members of the Royal Society, the full name of which was The Royal Society for Improving Natural Knowledge by Experiments. That society had had its beginnings in Oxford back in 1645 when "divers worthy persons inquisitive into natural philosophy and other parts of human learning and particularly of what hath been called the New Philosophy and Experimental Philosophy" had begun to hold weekly meetings to discuss their findings. Charles II had chartered this Society in 1660 and limited its number to fifty-five members, even going so far as to offer to become a member himself. That was just six years before the *Académie des Sciences* had been founded in Paris. The Royal Society enjoyed a great reputation as time went on. It was altogether natural that Franklin should want to send his paper on electricity and lightning to be read at one of their meetings.

But the members of the Royal Society refused to pay any attention to Franklin's theories. However, some men in Paris, who were more open-minded, tried erecting some steel points which reached about forty feet into the sky, in an effort to draw the lightning down. They were not successful. "They cannot get high enough," Franklin must have thought as he read of their experiments. Would it be possible to erect any points in America high enough to draw the lightning from the sky?

A new church was being built in Philadelphia at that time. It was Christ Church, whose delicate spire had been designed by Christopher Wren. Franklin must often have walked by, when they were building it. Perhaps when it was finished, it would be tall enough for the great experiment.

The workmen must have been slow at their building, for apparently Franklin grew tired of waiting for them to finish. One day he thought that it would be possible to reach higher into the clouds by a kite than by a spire. Could he perhaps draw the lightning down the kite string?

He made his kite of a silk handkerchief spread over crossed sticks. No one was with him but his son, a youth of about twenty, when he took it out into the fields to raise it. He tied some metal keys on the kite string to attract the lightning, and watched the kite toss about among the thunderclouds for a long time. If there was electricity among the clouds, he had no way of knowing it. He grew tired of waiting.

At length a shower of rain wet the kite string. And he observed that the fibres of the string raised themselves a little as if they had become alive. In excitement he raised his hand and pressed his knuckles against the keys. He felt the shock of electricity quiver through him.

So now he knew that the lightning and electricity were one. He continued his experiments, and wrote in 1752, "I erected an iron rod to draw the lightning down into my house, in order to make some experiments with it, with two bells to give notice when it should be electrified."

And now rumors of his work began to spread abroad, and many other men began trying similar experiments. One of them, a Russian in St. Petersburg, George William Richmann, was killed by the lightning in 1753, but Franklin was more fortunate—he was not hurt.

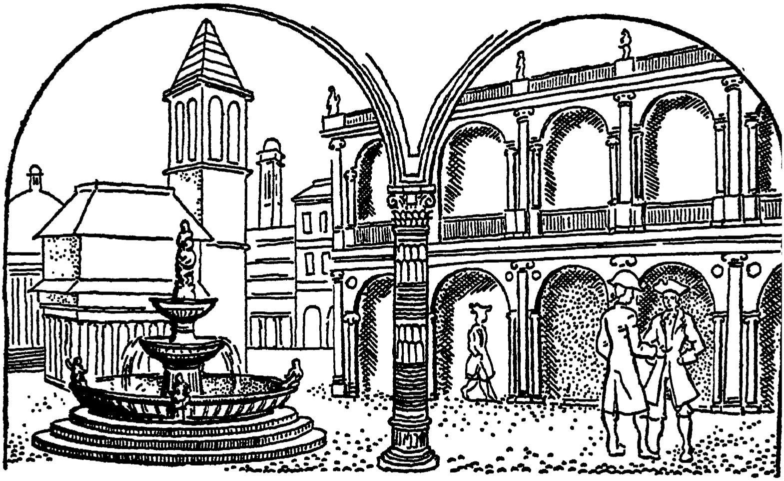
It was in 1750 that Franklin first felt the electricity quivering against his knuckles, but for some reason he did not report his experiment until October 19, 1753. Then he wrote an article on

the Electrical Kite in the *Gazette,* and at the same time he put an advertisement in *Poor Richard's Almanac* under the heading "How to Secure Houses etc. from Lightning." The advertisement read, "It has pleased God in his goodness to mankind at length to discover to them the means of securing their habitations and other buildings from mischief by thunder and lightning."

But it was not until 1760 that the first house in Philadelphia was equipped with lightning rods. There was strong objection to them, for many clergymen said that it was the will of God that there should be destruction by lightning, and the will of God should not be interfered with. John Winthrop, who established the first laboratory of experimental physics at Harvard, answered these worthies by saying, "It is as much our duty to secure ourselves against the effects of lightning as against those of rain, snow and wind, by the means God has put into our hands." So the use of lightning rods continued.

Franklin went on making his lightning rods, and he and his friends continued their experiments with the "electric fire." One of them, Ebenezer Kinnersley, went all the way to Boston to give lectures about their discoveries, and Faneuil Hall is said to have been crowded with people who wanted to hear what this mysterious fire from heaven was, and how it behaved.

But even while these things were going on, there were other men working at electricity, and finding new sources of it—not in electricity made by friction now, not in the lightning—take Luigi Galvani of Italy, for instance——



7. *The Twitching Frog Legs*

Professor Luigi Galvani was an Italian, and his story concerns itself with a pair of frog legs that lay on a table in his laboratory. For Galvani was a professor, not of electricity, but of anatomy, and the place where he worked was Bologna, in Italy.

Bologna is a quiet old city of colonnaded walks and carven churches. It is famous for the beautiful frescoes in the palaces of its nobility, and for the delicate carvings of its fountains. But it is most famous for the Institute where Galvani taught. For to it students flocked from every part of Europe. There were ten thousand names on its rolls at one time. It was so progressive that it allowed women on its faculty as well as men. And in its laboratories the first dissection of a human body had been made. Galvani must have counted himself fortunate when he received his appointment there in 1773.

He had not thought that he would be a scientist at all. He

first studied to be a monk, then took a degree in law. But finally, perhaps under the influence of his friend Beccaria, who was on the faculty of the Institute, he decided to study anatomy, and rose quickly to a position of importance on the faculty.

Perhaps Galvani's devotion to anatomy was not altogether disinterested, for Beccaria had a dark-eyed daughter who became Galvani's wife. And it is this marriage which brings us, in a roundabout way, to the frog legs and to Galvani's discovery. For, according to legend—and legend is in this case the only source of information that we have—Lucie Galvani was ill. Galvani had called upon a physician to attend her, and the physician had prescribed for her a nourishing broth of frog legs. So far the story seems credible enough, but the next part of it seems harder to understand.

How did the pair of frog legs, prepared and ready for the soup kettle, happen to be lying there on the metal top of the table where Professor Galvani was working? That is a question to which no historian has supplied an answer.

At any rate, they were there, and it happened that one of the assistants touched them with a scalpel, whereupon to his surprise the legs began to move and twitch. In his excitement the boy called the professor, and the other assistants came too, to see what he had found. A circle of faces looked down at the laboratory table where the frog legs moved and twitched as the scalpel touched them, and there was a murmur of talk as they debated about the moving muscles.

Professor Galvani was determined to find out more about the strange occurrence. He took several pairs of frog legs and hung them from copper hooks which he attached to the railing of his balcony. Whenever the wind blew, so that the frog

legs touched the iron railing, they quivered and twitched in the same odd manner. What made them do it? He could think of no reason except that there must be electricity in them—animal electricity. The idea fascinated him. Was there electricity in every animal then, in every person? Was electricity the same as life?

The idea of animal electricity was not a completely new one to Galvani. He was a thorough student, and he knew the classics well. Aristotle had written long ago of the torpedo fish, that "causes and produces a torpidity upon those fishes it is about to seize, and having by that means got them into its mouth, feeds upon them. . . . The same fish also has the power of benumbing men."

And Plutarch had also written about the torpedo fish: "It affects the fisherman through the drag-net, and, if any person pours water on a living torpedo, the sensation will be conveyed through the water to the hand."

Even in Galvani's own time, a Dr. Walsh of Philadelphia had written a paper about electric fish. He wrote that fish called "rays" having this electric property were common in the Bay of Biscay, and that sometimes they weighed as much as eighty pounds. Such a fish could curl around its prey and kill it with an electric shock.

No one knew what the mechanism of these strange fish was like, nor why they had this mysterious power. But now Galvani, looking at his twitching frog legs, felt that he knew. There is electricity in every living animal, he said. In greater or less amounts it is in the muscles of all living creatures and of men themselves. After death the electricity soon disappears, but while they are alive they are electric. What it is, Galvani said,

I do not know. But that it is there, I have no doubt. Eagerly he set about fresh experiments. Soon he was ready to publish his findings in a scientific document written in Latin.

When Galvani's paper was read by the scientists there was a furore among them. "A great discovery," some of them said. "Animal electricity indeed!" said others. "The idea is nonsense. There are of course electric eels and fish, but otherwise electricity is made by friction machines, to be stored in Leyden Jars, or drawn from the sky as lightning."

Galvani heard the disputes and arguments that his paper had stirred up, and clung to his claims. There is electricity in every animal, he said again and again.

Gradually, one after another, his colleagues deserted him. The idea was too fantastic. There was not enough proof.

And now, as if these difficulties were not enough, his wife died and sorrow overwhelmed him. And finally, to cap it all, his teaching career came to a sudden end.

For in 1796 the triumphant Napoleon had swept across the Alps and down into Italy. And in 1804 he had placed the crown on his own head and become Emperor of France and of the dependent states. And now old and young must swear to regard Napoleon as the "agent of God's power on earth." The words of an older catechism had been altered to apply to him:

Question: What are the duties of Christians toward those who govern them, and what in particular are our duties toward Napoleon I, our Emperor?

Answer: Christians owe to the princes who govern them and we in particular to Napoleon I, love, respect, obedience, fidelity, military service, and the taxes levied for the preservation and defense of the Empire and of his throne. We also owe him fervent prayers

for his safety and for the spiritual and temporal prosperity of the state.

Question: Why are we subject to all these duties toward our Emperor?

Answer: First because God, who has created empires and distributed them according to His will, has by loading him with gifts both in peace and war, established him as our sovereign, and made him the agent of his powers and his image upon earth.

Thus were the rights and duties of every citizen in Napoleon's empire clearly set down. And every teacher and every scientist and everyone else was made to subscribe to them.

But Galvani did not feel that he owed such service to Napoleon. He was a scientist, accustomed to consider the immutable laws of nature. He had read the great French philosophers and had taught his students to question every statement of fact, to accept nothing until it had been proved. He had no proof that Napoleon was the agent of God on earth. He refused to swear the oath of allegiance to him.

It is dangerous for a university professor to defy an emperor, particularly if that emperor is Napoleon. It was not long before Professor Galvani found that his license to teach at Bologna had been taken from him. He was in poor health, and his savings were soon spent. At forty-one, still talking of animal electricity to any that would listen, he was near the end of his rope.

But if he was poor, and lonely because of Lucie's death, he was not without friends. They worked tirelessly and brought influence to bear, and finally succeeded in having him reinstated at the Institute. But it was too late then, for by that time he was dying.

He had of course been right in saying that there is such a

thing as animal electricity. But that was not what had made the frog legs move that morning when they lay upon his laboratory table in Bologna. The brilliant Alessandro Volta was to show that there was another cause, and in showing it to set men working in a new field—the field of current electricity.

8. The Pile of Metal Disks

The arguments about Galvani's animal electricity went raging back and forth across Europe. In every place where two or three scientists met together, in every laboratory and every club, his ideas were discussed.

Animal electricity? Could there be such a thing as animal electricity? If it was not animal electricity, what was it that had made the frog legs twitch?

Scientists have always prided themselves on being careful, and cool in their judgments; on not making any decision until all the facts are known. But they forgot about these things and ranged themselves into two opposing camps when it came

to this discussion. Most of the German scientists supported Galvani's view; most of the French ones opposed it. And in Italy Alessandro Volta led the enemies of Galvani.

Brilliant, rich, assured, Volta lectured to his classes at the University of Pavia, and students sat spellbound as they watched his experiments. What he said they believed even when they could not follow his intricate and skillful demonstrations. Now he was saying that Professor Galvani had been utterly mistaken in assuming that there was electricity in a frog's legs—an assumption that he had no means of proving.

Why then did the muscles twitch if there was no electricity in them? Volta had another explanation. He pointed out that the frog legs had lain on a metal table, and the boy had touched them with a scalpel of another metal. He pointed out too that when the frog legs hung from brass hooks on the balcony, the wind blew them against an iron railing.

It was contact between two dissimilar metals that had created electricity, he said. The moisture in the frog legs between them made the electricity stronger. But there was no electricity in the muscles themselves.

With great energy and patience Volta set about to prove his contention that contact between two different metals when in the presence of briny or acid moisture will create electricity. He tried putting little disks of different metals together, first seeing that their surfaces were moistened. Before long he had collected a whole heap of metal disks. Copper and zinc were the metals he was most successful with. Before long he had tried making a tall pile of these: first a copper then a zinc disk, then a piece of blotting paper moistened in a solution of vinegar, then another copper and another zinc disk, then another

piece of moistened blotting paper, and so on until he had a dozen pairs of metal disks standing one on top of another. Then he was ready to show how he could draw a steady current of electricity from the pile.

Here, then, Volta had produced electricity in a new way. It had been produced by friction machines; Benjamin Franklin had drawn it down from the clouds on his kite string. But here was Volta, drawing it steady and strong from a pile of metal disks.

On March 20, 1800, Volta wrote about what he had done to Sir Joseph Banks, president of the Royal Society in London. He described his pile of metal disks, and also what he called his "crown of cups," a series of cups in which strips of metal were suspended in an acid solution which produced the same effect. Sir Joseph Banks published the letter far and wide. Volta, he said, had made a great contribution to science.

Now honor followed honor for the great Volta. A paper describing his achievement was printed in the *Philosophical Transactions,* which is a learned journal published in London. He was invited to become a member of the Royal Society, London's most honored scientific group. Everyone talked of him: there seemed no limit to the amount of current that he could draw from his magic pile, no limit to the new experiments that could now be made.

The climax of Volta's glory came in 1801. Then Napoleon Bonaparte sent him a summons to come to Paris and to bring his pile of disks to exhibit to the Institute of France.

And finally, not content with all this, Napoleon had a blazing gold medal made, and presented it with great ceremony to the inventor of the Voltaic pile. So glory was piled on glory

for him, as he himself had piled disk on disk, until he died at last, rich and respected, an old gentleman of eighty-two.

The work that Volta had done merited all the honors that were paid it. Before his time electricity had been produced by friction, but he had found a way of making it in greater quantities. Now he could make it flow steady and strong along a wire as water flows through a pipe. A unit of electromotive force was to be called a "volt" in his honor.

Now more and more men began to experiment with current electricity. One of them, André Marie Ampère, the lonely Frenchman, worked tirelessly, though wretchedly, to find out how current electricity behaved, and to establish the great truth that there is a connection between electricity and magnetism.

9. *"The Longest Life Is Brevity"*

Just as a man going into a new country may hear of several paths across the mountains, yet not know very definitely the resources of the new territory that he has discovered; so new approaches to electricity were being found, yet very little was known about its properties or how it could be used. André Marie Ampère, a melancholy and lonely man with a brilliant mind, took another step toward understanding the force that was still so surrounded with mystery.

André Marie Ampère was growing up when the Revolution swept across France. He was eighteen when he heard the revolutionists enter his father's house in Lyons where he had been born; he heard them taking his father, the *juge de la paix,* to prison; he knew when they sent his father to the guillotine.

For a year after that his mind was like an unwound watch: his outward appearance was the same, but the spring within him had lost its tension. He sat staring at the sky, or heaping up sand into little mounds.

His mother watched him as he sat, heedless of the life that went on around him, looking at nothing. He had been a bright boy in the days before the Revolution. Even before he learned to walk he had known how to count and to add and subtract, and his mother, fearing that his mind would be hurt by too early development, had taken pens and papers away from him. But she had returned to find him scratching numbers in the sand with a sharp stick. She took this to mean that he would be a genius.

As time passed, his father also felt that he had the seeds of genius in him. He began to teach him Latin and Greek and such other matters as a learned person of his time should know. But Ampère had little interest in them; he wanted to study only mathematics. He had a passion for mathematics. He taught himself the mathematics his father could not teach.

Once he asked to borrow a book on mathematics from a neighbor. "It is written in Latin," his father said. André had never been willing to learn Latin. "I could learn it if that is necessary," he said now, and he began to study the hated language in order to be able to read more about mathematics.

But now his father the judge had been killed in the Reign of Terror, and the boy who was to have been a genius sat staring vacantly at nothing.

A year passed, and the despair of the boy's mother grew deeper. Then, by accident, he picked up a copy of Rousseau's great book on botany. He read it, and into the depths of his

blank mind the glow of Rousseau's enthusiasm penetrated. He read of plants and flowers, their beautiful structures, their curious root systems. He took a walk into the fields.

It was not long after this that he began to read Horace; and came upon the ode on the beauty and the brevity of life which the Roman poet addressed to Leuconoë. He read the words again and again:

> It is not right for you to know, so do not ask, Leuconoë,
> How long a life the gods may give, or ever we are gone away:
> Try not to read the Final Page, the ending colophonian,
> Trust not the gypsy's tea-leaves, nor the prophets Babylonian,
> Better to have what is to come enshrouded in obscurity
> Than to be certain of the sort and length of our futurity.
> Why, even as I monologue on wisdom and longevity
> How time has flown! Spear some of it!
> The longest life is brevity! [1]

The longest life is brevity. Life might be short. Yet how much of beauty there might be in it, if he could seize it; if he could but grasp it before it was gone from him.

Slowly his faculties were returning to him.

Now André Ampère decided to be a naturalist. He would study plants; he would be close to them in sun and rain and wind. At twenty he met Julie Carron, who shared his love of nature, and they were married, and they had a son.

André Ampère gave private lessons in mathematics now to support his family. Doubtless he would have preferred to teach botany, but there was no one who wanted to study it. Julie was not very strong. There were doctor's bills and other bills.

[1] Horace, *Ad Leuconeum*, translated by Franklin P. Adams.

Julie's parents wanted him to be a silk merchant, but his old love for mathematics and science was still in him. That was why he became a teacher of physics and chemistry at the Central School of the Department of the Aisne.

With his natural talent for mathematics, Ampère felt that he ought to be able to find a better position than that at the Central School. He found a curious way of getting one.

He wrote a book which he called *Considerations on the Mathematics of Gambling.* In this he proved that if a gambler played long enough, he was bound in the end to lose. The subject was such an odd one, and the mathematical method he used so brilliant, that the attention of many mathematicians was attracted to it. It was not long before he was offered a good position in a newly formed school of physics and chemistry at Lyons. He and Julie felt that they were at the beginning of a life of peace and security. Then Julie died.

When his father had died on the scaffold Ampère's mind had ceased to function, like a watch run down. At the death of his wife he continued to work. But now he, who was beginning to be a distinguished scientist, became for a time troubled, fearful, hesitating. The only thing that he could do, it seemed, was work. The part of his mind that worked seemed to be separate from the part that was unable to face the other facets of his life. He threw himself into his studies; he toiled long hours, carefully, meticulously, making himself forget.

His wife had died in 1804, when he was twenty-nine. The next year he went to Paris and became associated with the *École Polytechnique.* There he stayed for twenty years. More and more honors and distinctions came to him. He was made a member of the French Academy and of the Institute of France.

He read papers before learned societies; distinguished scientists, traveling through Europe, counted their journeys lost if they did not stop to see him. He received them amiably and pleasantly; he took the various honors and distinctions as they came, yet now his heart was not in his scientific work. He was deeply interested in questions of religion and philosophy, and spent his spare time talking of life after death and similar questions, with a few chosen friends.

He wrote in the year after his wife died, "My life is a circle. . . ." But he might have written the same thing at any time until his death at forty-one.

> My life is a circle, with nothing to break its uniformity. . . . I have but one pleasure, a very hollow and artificial one, and which I rarely enjoy, and that is to discuss metaphysical questions with those who are engaged in this science in Paris and who show me more kindness than the mathematicians. But my position obliges me to work at the pleasure of the latter, a circumstance which does not contribute to my diversion, for I have no longer any relish for mathematics. Nevertheless since I have been here I have written two treatises on calculation which are to be printed in the Journal of the Polytechnic school. It is seldom except on Sunday that I can see the metaphysicians such as M. Maine de Biran, with whom I dine occasionally at Auteuil where he resides. It is almost the only place in Paris where the country reminds me of the banks of the Seine. . . .

A lonely man was Ampère now, finding his only pleasure hollow and artificial, finding his fellow mathematicians unfriendly, finding in himself no longer any relish for mathematics. He married again in 1806, but little is told of this marriage. Yet his mind worked on, brilliant, methodical, accurate, as if it

was an instrument of great precision, completely separate from his body.

What was the work to which André Ampère devoted his industrious hours? He was experimenting with electricity—electricity and magnetism. He knew that there was some relation between the two. The Danish scientist Oersted had proved as much by experiment in 1820. Oersted had shown that he could make a compass needle move when he placed it near a wire charged with an electric current. Now Ampère tried Oersted's experiment himself. By careful mathematics he was able to work out the relation between the strength of the current and the degree to which the compass needle turned. He could formulate an exact rule for measuring the movement of the needle by the strength of the current.

Then he went on to experiment further with wires that had electricity running through them. When he laid two of these wires near each other and let the current flow in the same direction, they seemed to draw closer together though they did not touch. But when the current flowed in opposite directions they drew apart. The area around the wires was affected by the electricity in them. This area was later to be called the electric field.

In time Ampère tried coiling the wire around a piece of iron. When the current passed through the coil, the iron became a magnet. This was an extraordinary thing. The iron bar had apparently taken on life, simply because it had been near the coiled wire where the current was passing. He pondered on this fact, and finally came to believe that every atom in the iron bar had become a magnet because of the electric current that flowed around it.

So you could make and unmake magnets at will. The practical application of this fact may not have occurred to Ampère, but it was to have the greatest usefulness. For by making and unmaking magnets in this way, it was possible for later generations of men to make telegraphs and electric doorbells, and to lift heavy piles of metal from one place to another.

But Ampère was much more interested in the theories of electricity and magnetism than in their practical application. Watching his small bar of iron as it turned into a magnet with the electric current flowing round it set him to wondering about that great magnet the earth with its north and south magnetic poles. Was the earth a magnet too with electric currents sweeping round it as it turned? He had no way of proving this, but it seemed to him that it was probably true.

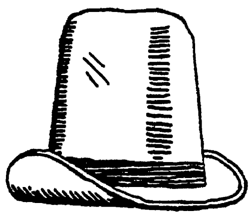
Ampère published a paper giving the mathematical theory of his discoveries in 1827. A later scientist, James Clerk Maxwell, said that his research was "perfect in form and unassailable in accuracy."

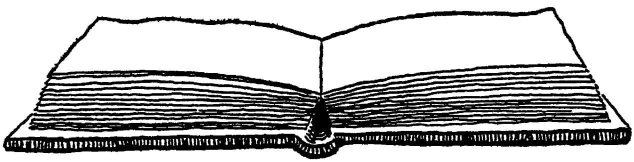
But though Ampère's work won much respect from his fellow scientists, he was apparently not greatly interested in his findings himself. William Gilbert would have invited the Queen to see, had he made any such discoveries; Franklin would have asked his friends, perhaps, to another electrical party; Du Fay, who hung himself up on silken cords, to watch the electric sparks go shooting from his body, would doubtless have thought of some dramatic way of telling the world this new-found truth —magnets are caused by small electric currents. It is possible to make a magnet by placing an iron bar in a spiral coil through which a current passes.

But Ampère, who did the hard mathematical calculations

that were to prove these things true, put on his hat and went to argue about life and death with his friends M. de Biran and M. de Tracy.

Though he found no joy in it, Ampère had nevertheless done great work. Later scientists named a unit of electricity an "ampere" in his honor, and Michael Faraday, working in the Royal Institution in London, took up the exploration of magnetism and electricity where he had laid it down.





10. *The Bookbinder's Apprentice*

When André Marie Ampère died in 1836 in Marseilles the news of his death was sent back to Paris by semaphore; but that very same year Samuel F. B. Morse began his experiments on the telegraph, which Ampère's work made possible. Meantime, Ampère's discovery had stimulated a great many scientists. Magnets could be made at will by turning on an electric current, he had said. If this was true, would the reverse be true also? Could electric currents be derived from magnets? It was Michael Faraday who asked himself this question: who set about trying to extract electricity from magnets. And Faraday's work was to change the world more than he could guess, for it set the motors running and lights burning everywhere. He would have laughed to think of the wheels that his work in the laboratory of the Royal Institution in London were to set in motion.

Young Michael Faraday lived with his mother and father and sisters and brothers in rooms over a coach house at Jacob's Well Mews in Manchester Square, London. When his father died, his mother moved to humbler lodgings in Weymouth Street and tried to support her family by taking lodgers, but

it was hard for her to get along. That was why Michael Faraday went to work when he was thirteen as errand boy for Mr. George Riebau. The sign which hung over the door of Mr. Riebau's shop announced that he was in the business of "bookbinding, stationery, and book selling." The great windows of the shop had small square panes with a book set up in each one of them for passers-by to see, and there were books placed on the shelves outside the street door to tempt anyone who wanted to stop and browse.

Riebau had an active, lively errand boy in Michael Farraday, and he soon grew fond of him. At the end of the year he took him for apprentice for a seven-year term. And Faraday set about diligently learning his craft, but he often stopped to read the books he bound. One of the books was an encyclopedia, and in it he read an article on chemistry. After that he saved his money to buy a cheap chemical apparatus, and carried it to the rooms on Weymouth Street where he lived with his mother. He wanted to try some chemical experiments after working hours. Next he read a book on electricity. Little enough was known about electricity, to be sure, but from the beginning Michael Faraday was fascinated by it. He read everything he could find on it.

One day a customer stopping at Riebau's shop told him of a series of lectures on natural philosophy by the great Sir Humphry Davy. They were to be given at the Royal Institution, where the most renowned men of London met. Nothing would do but that the young bookbinder must hear those lectures. He had a few shillings saved up to pay for them. Could the customer obtain tickets for him?

Sir Humphry Davy, big, handsome, self-assured, was the

great scientific figure of London at that time. When he lectured, a thousand people came to hear him. Among the thousand, the young bookbinder's apprentice sat, taking notes which he carefully copied and amplified later at Weymouth Street.

And now the years of Michael Faraday's apprenticeship were over, and he left Riebau's shop and became a full-fledged bookbinder, employed by de la Roche, a harsh, hotheaded tradesman. As he learned more about the ways of business he grew to like it less and less, and dreamed of being a scientist. But he had no influential friends, no money, no scientific education. He had only this great desire to "leave the world of business."

He wrote at last to Sir Humphry Davy asking if there was a place that he could fill in the great man's laboratory. As proof of his "earnestness," he enclosed copies of the lecture notes he had taken. The note which he received from Sir Humphry in reply has been preserved. It read:

Sir: I am far from displeased with the proof you have given me of your confidence, and which displays great zeal, power of memory and attention. I am obliged to go out of town and shall not be settled in town till the end of Jan. I will then see you at any time you wish. It would gratify me to be of any service to you; I wish it may be in my power.

I am, Sir,
Your obdt, humble servant
H. Davy

So it must have been about the end of January that the coach of the great Sir Humphry came rumbling into Weymouth Street, and that a footman rapped on the door of the house where Faraday and his mother lived, with a note asking him to come to see Sir Humphry next day.

Thus Faraday became Sir Humphry Davy's assistant at the Royal Institution, and they worked together on a safety lamp for miners to wear in their hats. Faraday's salary was twenty-five shillings a week.

Before very long Sir Humphry Davy with Lady Davy planned a tour of Europe, and Faraday was invited to come with them as secretary. The trip had certain difficulties, for Sir Humphry was without a valet, and wished Faraday to act as body servant, a post which the proud young man found very humiliating. Lady Davy proved hard to get along with too: Faraday wrote: "She liked to show her authority and at first I found her extremely earnest of mortifying me."

But despite these things the entries which he kept in his diary on the trip reflect joy and excitement in every passage.

> October 13, 1813. This morning formed a new epoch in my life. I have never before, within my recollection, left London at a greater distance than twelve miles.

Then he tells of the "luminescence" of the sea at night, the bustle of the Customs House, the Louvre—which seemed to him to prove the French a "nation of thieves."

In France the great Ampère presented him with a lump of stuff made of seaweed which gave off a purple vapor when it was heated, and he borrowed a Voltaic pile from a scientist named Chevreul. In a railroad carriage in France he had a glimpse of Napoleon, "sitting in one corner of his carriage, covered and almost hidden by an enormous robe of ermine, and his face overshadowed by a tremendous plume of feathers, that descended from a velvet hat."

So they traveled to Lyons and Montpellier and Aix and Nice, and crossed a snowy Alpine pass, and came to Turin at carnival

time, and saw Galileo's telescope in Florence, and stood in the Colosseum of Rome by moonlight, and ascended Mount Vesuvius. At Milan, Signor Volta came to see Sir Humphry Davy, and Faraday remarks that he was "an hale, elderly man, bearing a red ribbon and very free in conversation."

So eighteen swift months passed, and soon he was writing his mother from Brussels a letter which announced his return to England:

> Adieu till I see you, dearest Mother; and believe me ever your affectionate and dutiful son,
>
> M. Faraday
>
> (P S) Tis the shortest and (to me) the sweetest letter I ever wrote you.

Then Faraday was back in London again, working in his laboratory, living with his mother, going to the Sandemanian Church on Sundays. It was at the Sandemanian Church that he met Sarah Barnard. the daughter of a silversmith. She was twenty, and he was twenty-four.

Michael Faraday had once written in his journal that love was only a nuisance, but on July 5, 1820, he wrote to Sarah Barnard:

> You know me as well or better than I do myself. You know my former prejudices, and my present thoughts—you know my weaknesses, my vanity, my whole mind; you have converted me from one erroneous way, let me hope you will attempt to correct what others are wrong . . . again and again I attempt to say what I feel, but I cannot. Let me, however, claim not to be the selfish being that wishes to bend your affections for his own sake only. In whatever way I can best minister to your happiness, either by assiduity or absence, it shall be done. Do not injure me by withdrawing your friendship, or punish me for aiming to be more than a friend by making me less; and if you cannot grant me more, leave me what I possess, but hear me.

In May 1821, Faraday's position was changed from lecture assistant to superintendent. But his salary remained £100 a year.

In June they were married. Only a few friends came to their simple wedding. Faraday said that he wanted it to be "just like any other day. . . . There will be no bustle, no noise, no hurry. . . . It is in the heart that we expect and look for pleasure." The happiness which they expected and looked for was to last for almost fifty years.

Humphry Davy's experiments at this time were in chemistry, and with these Michael Faraday assisted him, often going beyond his chief in the originality of his investigations. They made some studies, for example, in aniline dyes, and it was Faraday who discovered a new base for these dyes called benzol. Davy recognized the talents of his young assistant, and before long he suggested that he be made director of the laboratory, a position which, while it carried little prestige with it, nevertheless gave him an opportunity to plan his own experiments. As director, Faraday arranged for weekly meetings with the members of the Institution in order that he might keep them up to date on new discoveries and inventions. This brought a certain amount of attention to Faraday, so that he soon found himself with many opportunities to lecture, and various offers of positions with large salaries.

But Faraday's real interest was in research. More and more his efforts were turning from chemistry to experiments with electric currents. He was especially interested in studying the electric field that lay around a wire through which a current passed.

Eventually Sir Humphry Davy became jealous of his young

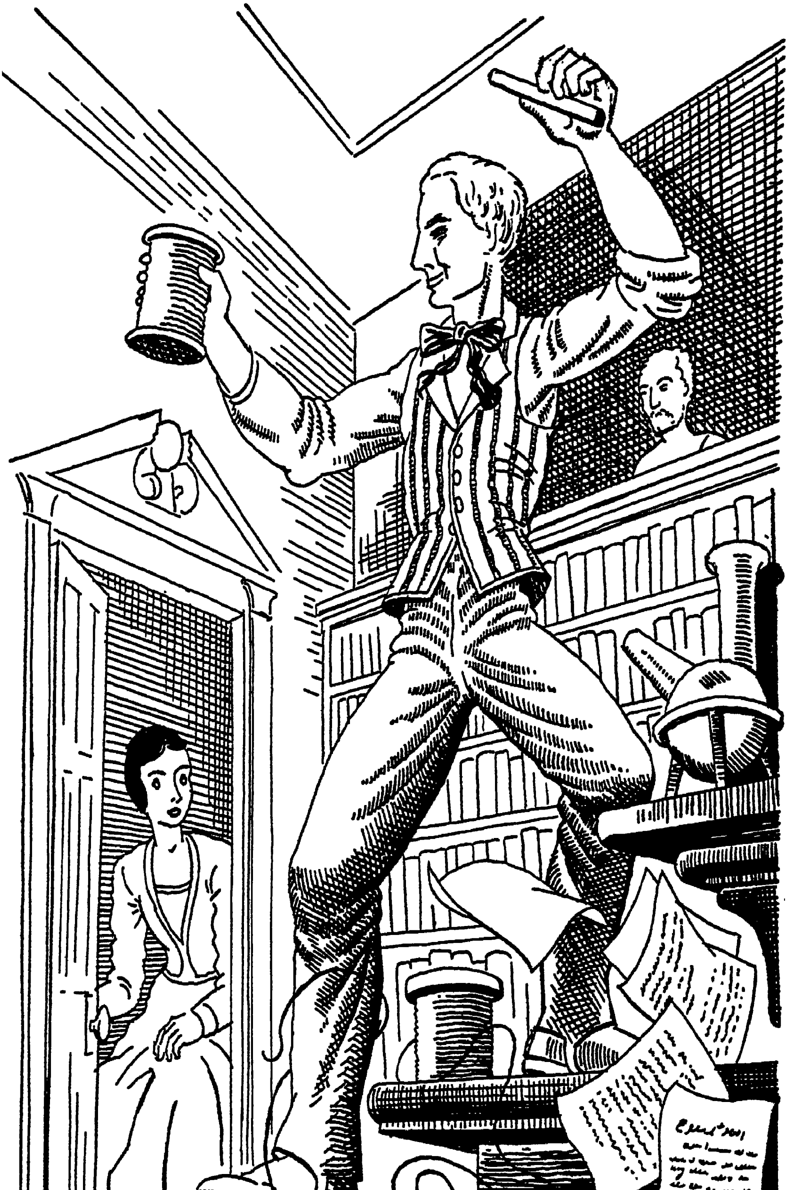
assistant, tried to belittle his work, and had him blackballed from election as a member of the Royal Institution, which was an honor which many thought he should have. But all this did not matter to Faraday. He continued in his unimportant post of director and went on with his work in the laboratory. He was coming now to his great task: he was trying to find a new way to make electricity, to make it from the magnetism of the earth.

Ampère had once made a magnet by wrapping a wire around a piece of iron and running a current into the wire. Could Faraday reverse the process? Could he produce electric current from a magnet? It was his habit to carry a small iron bar in his pocket. He had often wrapped this bar with copper wire and observed that when a current was passed through the wire the bar became magnetized. If only the current could be made to flow the other way, from the magnet into the wire.

In September 1831 he heard that Oersted had made a magnetic needle move from its north-and-south position by passing an electric current near it. After many trials, Faraday succeeded in repeating Oersted's experiment. He too made the magnetic needle move from its position by passing an electric current near it.

"There it goes! There it goes!" he cried, dancing around the room. Then he locked the door of his laboratory and took Sarah to Astley's Theatre to celebrate.

He worked on, patiently and persistently. It was not until October 17, 1831, that he succeeded in the task he had set himself. Then, according to his diary, he got hold of a cylindrical bar magnet three-quarters of an inch thick and eight and a half inches long. He wound two hundred and twenty feet of copper wire into a spiral coil, and found to his great excitement



that when the magnet was thrust into the coiled wire, electricity was produced in the wire. When he moved the magnet in and out there was a current. When it remained stationary there was none.

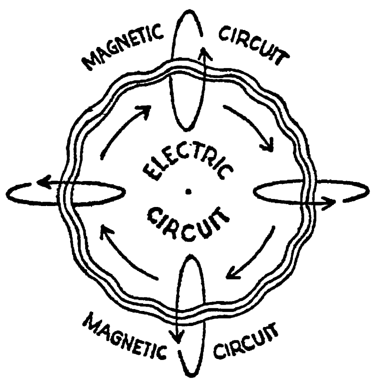
Michael Faraday, forty years old, jumped to the top of his laboratory table and danced. Electricity could be produced from a magnet. Motion was necessary to its production. Faraday himself was not sure of the reason. He thought it was because the metal must cut "magnetic curves," or "lines of magnetic force" as he called them—the magnetic field that surrounded every electric circuit.

Now he worked further to make a machine that produced electricity. He took a big horseshoe magnet and spun a copper disk round and round between its two poles. The moving copper disk cutting the magnetic field between the poles of the magnet produced a steady flow of electricity.

Here then was a new way of producing electricity. Gilbert had made electricity by friction, Volta had made it with his pile, but Faraday now was making it by motion between the poles of a magnet. It was possible to produce an almost inexhaustible amount of electricity in this way, for the earth itself is a magnet. He had, in fact, with his horseshoe magnet and his copper disk created the world's first dynamo.

But Faraday was not interested in machinery, and did not know what practical application would be made of his work. Money-making was far from his mind. He took out no patents on his invention. But he read a paper to the Royal Society explaining what he had done. He said, "I have rather been desirous of discovering new facts and relations dependent on magneto-electric induction. . . ."

At practically the same time that Faraday was turning magnetism into electricity, Joseph Henry, an American professor at Princeton, was doing the same thing. He wrote: "Before having any knowledge of Faraday's experiment, I had succeeded in producing electrical effects in the following manner . . ." and he then described how he drew an electric current from a moving magnet.



Later he took a journey to England and saw Faraday, and they compared their work. Faraday had already published his discovery, so the credit for producing electricity from magnetism went to him. But there was no feeling of jealousy on Joseph Henry's part. He wrote:

> I have sought . . . no patent for inventions, and solicited no remuneration for my labors, but have freely given their results to the world; expecting only in return to enjoy the consciousness of having added by my investigations to the sum of human knowledge.

So Faraday and Joseph Henry both discovered the great "new fact" that the magnetism of the earth, the universal source of electricity, could be tapped. Now Faraday turned his attention to other work.

There had been much discussion among scientists as to whether there might be different kinds of electricity. Was animal electricity different from that made by magnetism? Were these different from the electricity generated by the Voltaic pile? He concluded, "Electricity whatever its source is identical in its nature."

There were, moreover, all the various substances that could be used as conductors of electricity to study and compare. Faraday worked out a way to measure the power of a current by measuring the amount of gas generated when it passes through water.

And, too, he was interested in the behavior of light, and believed it had some relation to magnetism and electricity. In 1845 he wrote, "I . . . have at last succeeded in magnetizing and electrifying a ray of light. . . ."

With such work as this the years passed. Faraday was still slender, active, and gentle, but his hair was white. Once during those years his health broke down and he seemed to lose his memory. Then he was unable to work, and amused himself with riding on a four-wheeled velocipede that he had made, with going to the London Zoo to watch the antics of the monkeys in their cages. And he took special pleasure in watching acrobats, tumblers, dwarfs, and giants, and laughed at the belligerent antics of a Punch and Judy show. Once in the years of illness he and Sarah went to Switzerland, and he saw the waterfalls and glaciers, the cows and sheep with their herders, and the straggling goats. He always stopped to watch when he came to a blacksmith shop. "My father was a blacksmith," he used to say.

But after his term of illness he was back in his laboratory

again, working. Many honors were offered him as the years passed. They wanted him to be president of the Royal Society, to be professor at the University of London, to be knighted. But he refused these things, accepting only a small pension and, toward the end of his life, a house which Queen Victoria gave him on the green near Hampton Court. He accepted the house but continued to keep his rooms at the Royal Institution and often went to stay in them.

As he grew older, Faraday's memory became very weak. Often he could not remember one day the result of his experiment the day before. He worked for six weeks at an experiment, then looking back through his notes found that he had got exactly the same results eight or nine months before. He wrote his niece: "My worldly faculties are slipping away day by day. Happy is it for all of us that the true good lies not in them."

Toward the last, an old man of seventy-six, he liked to sit in a chair by the window watching the sunlight in his garden, and the coming of the rain. He was sitting there when Sarah came and found that he had quietly died. According to the custom of the Sandemanian Church, he was buried in perfect silence. The date was August 30, 1867.

The stone which marks his grave in Highgate Cemetery is inscribed simply "Michael Faraday." There are no words on it to show that this was the great man who first generated electricity from a magnet.

In 1867, when Michael Faraday died, even the scientific world had little understanding of his work in electricity and magnetism. An old scientific book published at this period speaks of his chemical experiments, and goes on to say that there was great need of a machine for generating electricity

but that up to that time no one had succeeded in making a practical one. The old engravings of this book show gentlemen in top hats and ladies in hoop skirts marveling at the intricacies of a machine for making Brussels carpet, and a little boy gazing in astonishment at a complicated webbing of a Jacquard loom. The intricate monsters of that early industrial age were turned by water power or run by steam produced by burning coal.

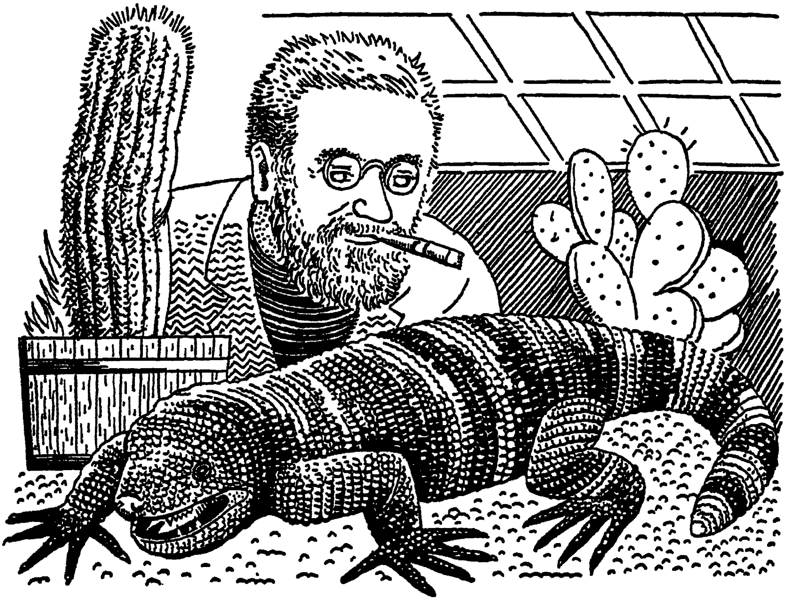
Meantime, in the Victorian world, the idea was gradually taking form that electricity could be made useful. Morse was inventing his crude telegraph, Bell his telephone, and Edison his electric light. The new devices were exciting but uncertain. In 1890 the Houses of Parliament in London were wired for electric lighting, but an urgent plea was made that the engineer keep the lights steady, "especially during the speaker's dinner." A tram car run by electricity was tried in England not long after that. Sir Oliver Lodge described its course as "impetuous" and said it finally "came to rest in a shop window." The progressive citizens of the little town of Godalming in England attempted to light their streets electrically, but laid their cables "innocently in an open gutter."

Meantime the smoke of more and more factory chimneys blackened the sky, for the great age of large-scale industry was under way. Near the mining districts and near the sources of water power the factory wheels spun round, turning out goods for eager thousands to buy. Based on Michael Faraday's experiments, electric dynamos had now been made, and many forward-looking business men wanted to use them instead of coal or water power. With the use of electricity, a factory would be cleaner: the smoke of the factory town would be done away

with. If power could be carried to the factory over wires, an industry might be established anywhere—not just near the coal fields or the waterfalls. There would be great saving of space in the factories themselves if steam boilers and water wheels could be done away with. Up to the end of the nineteenth century electricity had been a mystery dealt with by scientists or by showmen: could it be the property of great industrialists now?

By the turn of the century some big dynamos to run factory wheels had been designed; but many still thought it would be impossible to use electricity industrially. For one thing, engineers could not regulate the amount of current which was fed to a machine. Sometimes it was so weak as to be inefficient: but sometimes it was so strong as to ruin the machine altogether. Then too, there was no satisfactory way of transforming the alternating current which the dynamos produced into the direct current which would be more practical for industrial purposes. And, finally, it was found that when electricity was carried any distance along a wire there was so much leakage into the surrounding atmosphere as to make it very expensive. Engineers knew that if the current was sent along the wires at very high voltage, there was proportionately less leakage. But how this "stepping up" of power was to be done was another problem.

It appeared to the industrialists of the new age that not enough was known about electricity to make its use satisfactory. That was why they set up laboratories where electricity could be studied. It was in the great industrial laboratory of the General Electric Company that Charles Proteus Steinmetz worked.



11. *Proteus, the Old Man of the Sea*

Of course when Steinmetz stood on the deck of the French immigrant steamship *La Champagne* and looked for the first time at the Statue of Liberty, and when he stood before the brass-buttoned officials at Ellis Island, there was no thought of electric currents in his head, or of great industrial laboratories. Little work had been done in adapting electricity to industrial purposes then and the great industrial laboratories did not exist.

When Steinmetz came to America from his native Germany, having stopped for a while in Switzerland on the way, his name was Karl August Rudolf Steinmetz. His reception in America

was not a very cordial one. He had left Germany because of political disturbances, had borrowed money from a friend for his passage, bringing nothing with him of consequence but his brilliant scientific mind and his small misshapen body.

So when the immigration officials saw Steinmetz, hunchbacked, shabby, almost a dwarf with his four feet three inches, they asked him rather roughly if he had brought money to support himself in America. Steinmetz could not understand or speak English, but his friend Asmussen, who stood beside him, tried to explain that he was a brilliant mathematician. The immigration officials were not at all impressed, and announced that he must return to Germany.

But Asmussen had some money which he loaned to Steinmetz, and soon the two of them were ashore and on their way to Brooklyn to visit relatives of Asmussen. Before long Steinmetz was beginning to learn English and was looking around for work.

He found a place at last in Yonkers with a man named Rudolf Eichemeyer who had himself been a political refugee from Germany. The firm made machinery for hat manufacturing and electrical appliances. He earned twelve dollars a week, and saw in this a prospect of saving money to repay Asmussen.

Steinmetz was very happy in this arrangement. Eichemeyer gave him a free hand to work with electricity, and he lived with Asmussen, who had also found work near by. He liked America and decided at once to take out citizenship papers. It was at this time that he decided that his name, Karl August Rudolf Steinmetz, did not sound sufficiently American. He changed it to Charles Proteus Steinmetz. The Proteus was a nickname his fellow students had given him at Breslau. The

young scholars had remembered that Proteus was the old man of the sea who could change from a hurricane to a fire, from a fire to a sea serpent. Steinmetz was changeable like that. He rather liked his nickname: it suggested versatility and power. As he grew older he came to look more and more like a strange old man of the sea.

After Steinmetz had worked for Eichemeyer for several years the business was sold to a new company, the General Electric Company. That was in 1892. The president of this company, E. W. Rice, talked with Steinmetz, and described him afterward as "a small frail body, surmounted by a large head with long hair hanging to the shoulders, clothed in an old cardigan jacket, cigar in mouth. . . . I instantly felt the strange power of his piercing but kindly eyes. His enthusiasm, his earnestness, his clear conception and marvelous grasp of engineering problems convinced me that we had made a great find."

So when the General Electric Company took over the Eichemeyer business it took over the services of Steinmetz with it. Some of the company officials considered him Eichemeyer's "most pronounced asset." He went to work for the General Electric first in Lynn, Massachusetts, and later in Schenectady, New York. Other industries maintained laboratories to test their products or the materials they used, but the General Electric Company was the first industrial organization to maintain a laboratory for pure research.

Schenectady was a rather sleepy, quiet New York town. Perhaps that was why the General Electric Company chose it for its laboratories. Few people went there, and great work might be performed quietly, almost unnoticed by the public.

To Schenectady, then, the General Electric Company brought

its scientists, paid them good salaries, and let them do whatever research they cared most for. They made no stipulation that their work should be of immediate benefit to the company. It was simply understood that any discoveries or inventions the scientists made were the property of the company.

With the beginning of the General Electric Company a new era in scientific research was begun. Once scientists had tried to finance their own work and fared well enough if they were rich. But too often they were cold and poorly nourished while they tried to carry on important work in badly equipped laboratories. Some great scientific work had been done in university laboratories, to be sure; and some scientists had been supported by the bounty of kings. But, in general, unless a man had a private fortune of his own it was difficult for him to make a living and carry on his experiments at the same time. Therefore the great industrial laboratories were established. The big companies realized that if research was to go forward, the scientists who did it must be supported.

In the General Electric Laboratory Steinmetz was free to have whatever he needed, free to have assistants or not to have them, free to follow whatever complicated and intricate paths he wished. The laboratory in which he worked did not look impressive. It was furnished, to be sure, with enormous transformers and generators, but these were generally quiet: most of his work was done mathematically.

Generally the atmosphere of the place was a cloud of smoke, for few people had ever seen Steinmetz without a long, drooping cigar in his mouth. It was generally an evil-smelling cheroot. He tried to smoke cigars of good quality when his days of prosperity came, but he had grown so used to the cheap ones that

good cigars did not taste right to him. The story goes that when the General Electric Company tried to prohibit smoking in its buildings, and posted a large sign: "No Smoking." Steinmetz chalked a notice on the wall: "No Smoking—No Steinmetz." Whether this be true or not, the cigar smoke in his laboratory continued.

The smoke of the Steinmetz cigar was mingled often with the smoke of a frying pan in his laboratory. For Steinmetz spent long hours at work and often cooked lunch or supper over a little gas stove for himself and any assistants who were working with him.

Gradually Steinmetz became known as a great figure: people said he did what it was impossible to do. The men in the laboratory stopped talking when the little dwarflike figure came in. "Good morning! Good morning!" he is quoted as saying. "What's new?" That was how the working days began for almost thirty years.

During those thirty years Steinmetz worked out more than two hundred patents and assigned the rights for them to the General Electric Company. The most important part of his work was in the field of magnetism and electricity. Here he worked out a law, called the law of hysteresis, which made it possible to calculate in advance the amount of electric power which would be lost when current was sent over long distances. He also worked out a way of stepping up electric power so that it could be sent along wires in amounts which would prove most economical, and of transforming it again at the other end of the wire so that it would not ruin the machines in which it was to be used. The mathematical wizard could calculate all

this in advance, before the building of transformers, generators, and motors was even begun, and the engineers would know exactly what to expect of the electricity with which they were to work.

When he was not in the laboratory Steinmetz lived at first in rented houses. Here he amused himself with collecting cacti. The more queer and misshapen they were the better he liked them. He built a conservatory of his specimens and spent thousands of dollars on coal to keep the temperature at tropic heat.

If Steinmetz liked grotesque plants, he liked grotesque animals even more. He soon had a collection of alligators and lizards, as well as ducks and kittens. His favorite pet was a gila monster from Arizona which slept in his conservatory, waking up about once a month to eat an egg.

But in spite of these distractions and the fascination of his work, his life was rather lonely. The landlords of the various houses that he occupied objected to him as a tenant, because of his curious habits and what they regarded as his dangerous experiments. After a while he began to live at the laboratory altogether. One or another of his laboratory assistants used to live with him. But although they generally considered it a great privilege to be on such intimate terms with the great scientist, they grew tired of the monotony of his scrambled eggs and beefsteaks.

After a time Steinmetz decided to build a house for himself. It was to be a large, expensive house. He watched it as it gradually took shape. When it was finally finished he was reluctant to move into it. He could not bear the thought of being there alone. Then an assistant named Hayden who had been

living with him in his laboratory came to the rescue. Hayden tells of it thus:

The life in the laboratory was all right, but I was getting sick of it. Steak and potatoes every day. Just steak and potatoes. Sometimes just steak one day and just potatoes the next. I couldn't stand it. So I said, "I'm going out and get married." The Doctor said, "You'd better. Go ahead." So I went out and got married and we went to live over the other side of town. About the first night we were back from our trip a knock came on the door. It was the Doctor. You couldn't shake him. We asked him to stay to supper and he did. He used to come around nearly every day and pretty soon he asked me and Mrs. Hayden to come and live with him. You see, he wanted someone around the house. We moved in as soon as we could get some furniture, and we've been there ever since. From then on I always called him "Dad." He was like a father to me and Mrs. Hayden.

And he was like a grandfather to the three small Haydens that were born in his house, playing with them, and talking with them, and taking them for rides in a canoe which he kept on the river.

There followed high and happy days for Charles Proteus Steinmetz. His work with alternating current, his inventions in transformers and generators, were beginning to be recognized. His life with the Haydens was happy and serene. Union College, in Schenectady, asked him to become a member of its faculty, an arrangement to which the General Electric Company did not object, and which therefore did not interfere with the salary they paid him. Harvard gave him an honorary degree in 1902. In conferring it, President Eliot called him "the foremost electrical engineer in the United States and therefore in the world."

Up to Schenectady came a stream of visitors to see the man that people were beginning to call a wizard. In 1910 a group of Russians sent by the Czar to investigate the wonders of Western science called on him and found him in a bathing suit in his canoe. At another time Edison came to see him, and although Steinmetz did not think very much of his scientific ability, he found him a congenial guest. When it appeared that Edison was hard of hearing, Steinmetz tried conveying a message in Morse code by tapping on his knee. The story of a conversation tapped out on the knees of the two men went the rounds of the laboratories. Einstein, for whose work Steinmetz had great admiration, was another visitor.

And in 1922 Marconi came to see him. Marconi, like Edison, was not really a scientist; he was a practical inventor, but Steinmetz showed him his gila monster, and showed him the great advances in radio made possible by his work on transformers.

Steinmetz's great original work was finished. As he grew older more and more people visited him. Most of them could not understand his complicated mathematical theory, and saw in his big generators and transformers only mysterious and dreadful monsters. So Steinmetz decided that he would give them a display that they could understand. He invited a large number of guests and a host of newspaper reporters to his laboratory. There the visitors found a complicated collection of glass plates, wires, switches, a big generator, and the largest condenser or container for storing electricity that had ever been made. They saw also a replica of a little village with brightly painted houses, green trees, and a church spire.

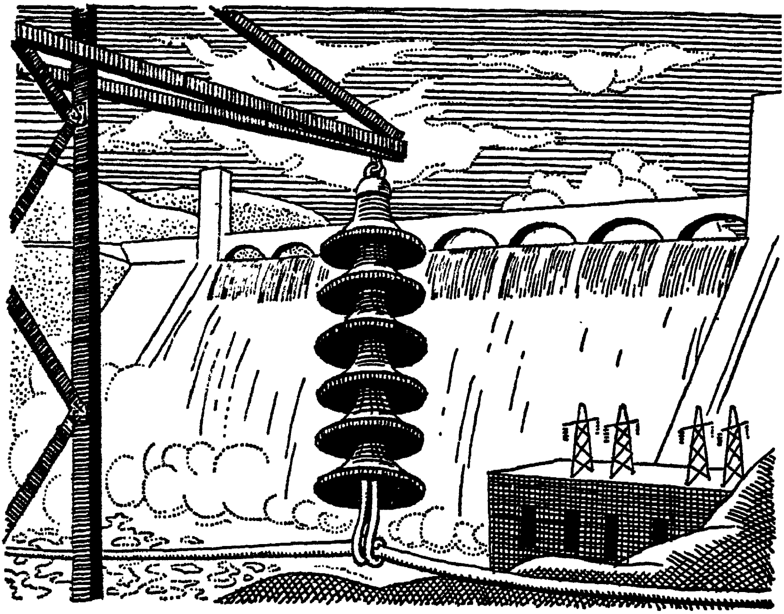
When all were ready the little hunchback touched a switch, the tubes in the generator began to glow, there was a long

pause, then a blinding flash of lightning and a crash of thunder, while the little village disappeared in a cloud of evil-smelling smoke. "Modern Jove Hurls Thunderbolts," the newspaper headlines read. One wonders what Benjamin Franklin would have thought of it.

There were no new principles involved in the artificial creation of the lightning. It was generally known that if you stored electricity in a condenser it would at last give off a flash. This was a bigger condenser and therefore a bigger flash than anyone had ever made before, that was all. It is strange to think that when he was doing his great creative work, comparatively few people had ever heard of Steinmetz, but after his creation of the lightning he was talked of everywhere. He made a speaking tour along the West Coast and audiences packed the halls wherever he spoke. But he was tired when he returned to Schenectady, and glad to be at home again in his comfortable house with the Haydens. He died there in 1923.

But the giant generators and the great transformers which he had designed were not dead, being made of metal. His transformers made it possible to carry current over meadows and valleys and up and down hills and across rivers, without loss of power. The energy of Peter Peregrinus' magnet, and William Gilbert's bit of amber, which Faraday had joined to make a motor, was increased in power and harnessed to set the wheels of a new age spinning.

Now in the coal mines much of the cutting and ventilating and hauling and pumping was done electrically. And electricity was used in the steel mills and in the rolling mills. Electric motors drove agricultural machinery, and electricity pumped the water across fields in great irrigation systems. Electricity was



the motive force that turned wheels of more and more factories now; while in the United States, Great Britain, Switzerland, Austria, and Italy, electric locomotives hauled the heavy thundering trains. In the Panama Canal electric windlasses hauled the ships through the locks; wherever excavation was needed electric cranes scooped up the earth in bites of a hundred tons apiece. Electric furnaces smelted iron ore now, and converted it into steel, and fused the various constituents together to make aluminum. Electric welding took the place of riveting to join the metal plates of battleships and airplanes. The new age—the electric age—had come.

And it was Steinmetz who had shown how the great power of electricity could be used for industry. But he had not explained what this electricity was. He did not know.

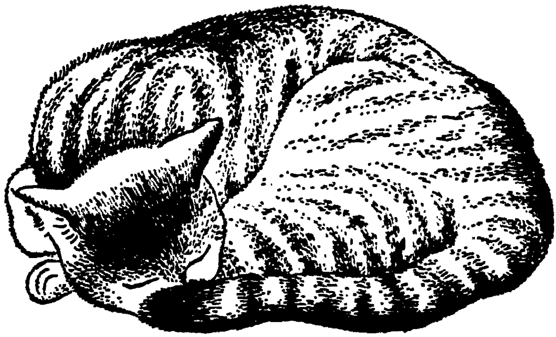
PART II

How They Studied Water, Earth, and Air

The statement of the Quaker
As he wandered through the peaceful English country:
"Atoms compose all earth and air and water."
The many men examining these atoms.
The discovery that they are made of particles of electricity.

(But what are particles of electricity?
Are they made of energy?
And if this energy should be released?

The vast labors
Of a host of men working
To split the most minute thing in existence.
The bomb.
The blinding light.



12. John Dalton and the Weather

"Clear tonight." John Dalton looked up at the sky, where the stars were twinkling in their accustomed places. "The atmosphere will probably be dry and cool again tomorrow. No sign of change." John Dalton called his cat, which came running in from the garden shadows, bolted his door, recorded his weather findings in a fat black notebook, blew out the lamp, and went upstairs. The rest of the household had gone to bed long ago.

In the morning he rose at eight, lighted the grate fire in his study, worked at his experiments, had dinner at one, tea at five, supper at nine, eating "a methodical amount of food." He tutored boys in mathematics to earn enough to keep himself going, bowled at the Dog and Partridge Green every Thursday afternoon, and drank a cup of tea and smoked a "churchwarden" before he walked home again. There were few changes in his existence. The only thing that really changed as far as he was concerned was the weather: perhaps that was change

enough, for the weather was to bring him the idea which was the great contribution of his life.

Mists and rains and clearing; damp air and dry air; days when frost lay on the ground, and days when there was sleet and snow; days of high winds blowing the clouds across the sky, and still days—if a man noted all these carefully, and checked them conscientiously with the aid of his thermometer and barometer, could he understand the rhythm of the weather? Would he be able to foretell rain, or sun, or fog, in advance?

Day after day John Dalton put on his broad-brimmed Quaker hat, his rather shabby coat, his stout leather boots, and, stick in hand, set out across the country to measure how much the rain had raised the level of a pond, how hard the wind was blowing on a neighboring hill. He was completely absorbed by such measurements and calculations.

Who was this man, so completely occupied with his own work? Where did he come from? What was his life to mean?

John Dalton's father had been a spinner who worked at a hand loom in the village of Eaglesfield, in Cumberland County, England. But the spinner had died in 1772, when John Dalton was only twelve. There was a large family of children, so it was necessary for John Dalton to shift for himself.

His parents, who were Quakers, had given him a good elementary education, so after his father's death John Dalton tacked up a sign on his father's barn door, announcing that he would open "a house of learning for both sexes at reasonable rates." "Free paper, pens and ink" were to be supplied to any who enrolled.

He had no difficulty in getting pupils. Some of them were only six or seven years old, some were gangling youths taller

and older than he was. It was not long before the school outgrew the barn, and accommodations were found in the near-by Friends' Meeting House.

But there were difficulties for the young schoolmaster. He could not find a way of teaching pupils of so many different ages all at once, and there was always the dread matter of discipline. After three years John Dalton gave up his school.

He thought for a time of going into "the agricultural business" with a rich uncle, but decided that such a life was not much to his liking. Then he tried to work the little patch of land that was his father's farm. And meantime he studied Greek, Latin, mathematics, and natural science in his spare time.

Finally he tied his possessions together in a big handkerchief, fastened the dangling bundle to the end of a stick, and set out down the road to the village of Kendal to teach in a school which his brother Jonathan conducted. The journey to Kendal took him through the village of Cockermouth, and here he saw an umbrella for sale. He admired it very much and decided to buy it: it was the first umbrella he had ever seen.

After he had worked with his brother for a time, he was offered a tutorship at Manchester College, and he agreed to try it. Although he did his best, it did not go off very well. He had a rather homely appearance and a gruff voice, and often his students could not understand what he was trying to say.

So he gave up his post at Manchester College, and issued some circulars offering subscriptions to a series of lectures on "the laws of motion, color, wind, sound, harvest moons, lunar eclipses, planets and tides." Subscriptions to the whole series were a half a guinea. Anyone paying a shilling extra would have the privilege of asking any question he liked at the end of

the lecture. But the lectures were not very popular: Dalton sought to make a little extra money by pressing flowers in books and selling them. He would fill a whole book of two quires for a guinea. He busied himself also with studying snails, mites, maggots, and other small flies and insects. "Some of these specimens may be thought puerile, but nothing that enjoys animal life, or that vegetates, is beneath the dignity of a naturalist to investigate," he said.

More interesting to him than flowers or insects, however, was the weather. He delighted in his recordings of weather conditions and measurements of rainfall and wind velocity. He tried to turn this interest to some practical purpose, and made crude instruments which he offered for sale to farmers. He could not see why they were not as interested in the weather as he was, since it certainly had a definite effect on their crops.

When it came to actually earning his living, though, he found that giving lessons to boys in mathematics was the most reliable way. He was not unhappy about it, though he enjoyed his scientific pursuits better.

He had only a few friends. Once the daughter of a Quaker, Mr. Johns, leaned out from the window of her house to bid him good morning as he passed up the street.

"My mother wishes to know how it is that you come to see us so seldom?" she said.

"I am thinking of coming to live with you," he answered in downright Quaker fashion. Thereupon he moved in and lived with the Johns family for more than thirty years.

In those thirty years he spent much of his time giving his lessons in arithmetic, but much of it also was spent in walking over the hills and moors, testing the atmosphere for humidity

or measuring the rainfall. The sight of him in his Quaker hat, his leather boots, and with his walking stick was a familiar one for miles around Manchester. Sometimes he went up into the Lake District or over into Scotland.

The more he worked with the atmosphere, the more he wondered how the air was made. Chemists before his time had established that air contained oxygen, nitrogen, carbon dioxide, and water vapor. But were these joined together in some kind of chemical compound? Or were they simply mixed together? If they were mixed together, why did they not sometimes separate? Why didn't one substance or another sink to the bottom? Wherever he went, up to the top of a hill, or down to the level of a lake's surface, the composition always seemed to be about the same. Was it the wind blowing through the air that kept it mixed up in exact proportions? It didn't seem likely.

One evening he was sitting before his fire, his cat on his knee. He had been on a long walk over the hills, making tests of atmospheric conditions. The clock ticked on the wall, the fire sputtered a little, the cat curled itself round and tried to put its head in under his coat. John Dalton put on his spectacles, and began to draw little designs on a sheet of paper. His pictures seemed to make the atmosphere substantial to him.

He tried to picture each element, each separate substance which, taken singly or in combination, makes up the whole of the material world.

He could mix them all together, he thought, yet each little figure kept its own identity, and each was mixed in and held in place by the others. Simple enough, it seemed.

And if this arrangement of separate little particles was true with regard to air, why was it not true also for water? Or for

earth? All matter must be made up of separate atoms—he drew separate little symbols to designate each one.

It was known that when mercury was heated in the air, a substance called mercurous oxide was formed. The atom of mercury had combined somehow with the atom of oxygen, Dalton imagined. He tried to show what had happened with his diagrams.

Gradually it appeared to him that the whole atomic scheme was simple enough. The world was built of little bricks, each brick an atom. Chemical change came through the joining together or separating of these atoms again. The clock ticked on while John Dalton drew his diagrams.

The idea that all matter is made of minute separate particles was an old idea: it did not originate with Dalton. But in Dalton's mind it worked itself out into a beautiful, reasonable plan. He bent over his diagrams, his steel-bowed spectacles on his nose. It was not necessary for him to experiment—he could work it all out with a pencil and a piece of paper.

All the atoms of which the world was made were not the same in size and weight, he said. But all the atoms of a certain element were alike: every iron atom resembled every other iron atom; every atom of sulphur was like every other sulphur atom.

Of course he could not see the atoms which were so real to him. They were so tiny that there were billions of them in every drop of water. But this made no difference to him. He worked and spoke of them as if they were tangible things. After a while he employed a Mr. Ewart to make some wooden models under his direction. They were useful in explaining his ideas to other, less imaginative people.

He must have wished often that he could weigh his atoms:

but they were much too tiny for anyone to weigh. He did conceive the idea that he might arrange the substances they made according to their relative weights. He succeeded in arranging fourteen elements in this way. His *Table of Atomic Weights of the Elements* was published in 1803.

In 1869 Dmitri Ivanovich Mendeleev, the Russian scientist, was to make a more complete table, and to find that the elements arranged by weight composed themselves into groups with similar characteristics. Mendeleev even prophesied certain new elements that were later found actually to exist. It must have been very exciting for the scientists who searched and found the elements that Mendeleev had guessed at, and so completed the table of ninety-two known elements. They could not know that in a later time men would be able to create new elements, besides the ninety-two, which had never existed in nature before. Strange and exciting were the discoveries to which John Dalton's theory was to lead.

But there was nothing strange or exciting about John Dalton himself. He lived on in Manchester, earning his living with his lessons in arithmetic. Each day-pupil paid him ten guineas a year, each night-pupil ten shillings a lesson. "And yet, in spite of all this, I am not able to retire," he said.

He did, however, have enough money to send a present to his mother occasionally. She still lived in Eaglesfield. Once he sent her a fine pair of wool stockings. She wrote to thank him saying they were lovely stockings, but she could not wear them to Friends' Meeting, for they were cherry red. Her letter surprised John Dalton: he was color blind, and had no idea that they were red. In fact, he thought the stockings he had sent her were drab olive-green.

The atomic theory which John Dalton had conceived so quietly became more and more talked about among scientists. In 1803 he was invited to London to discuss his ideas at the Royal Institution. One of the men who heard him talk was Humphry Davy, Michael Faraday's old master. Davy thought very little of Dalton's theory, and said so. But Dalton was untroubled by his pronouncements. "The trouble with Davy as a scientist," he said, "is that he does not smoke."

John Dalton never married. He said, "I haven't time. My head is too full of triangles, chemical processes and electrical experiments to think of any such nonsense." However, it cannot be denied that he found the ladies of London extremely interesting when he went there to lecture at the Royal Institution. "I see the belles of Bond Street every day," he said happily. "I am no more taken up with their faces than with their dress. Some of the ladies seem to have their dresses so tight around them as a drum, others throw them round like a blanket. I do not know how it happens but I fancy pretty women look well anyhow."

Gradually while John Dalton pondered on these things, and continued to earn his living with his tutoring, he was becoming famous. People were calling him "the illustrious author of the Atomic Theory." He must have been rather surprised at the attention they were beginning to pay him. He was invited to Paris, and given a great ovation there. The same Sir Humphry Davy who had scorned his atomic theory at first wrote him a letter asking him to take part in an expedition to the Antarctic. His scientific learning would be of great service on the expedition, he said. There is no way of knowing whether John Dalton smiled when he declined the invitation of the eminent scientist.

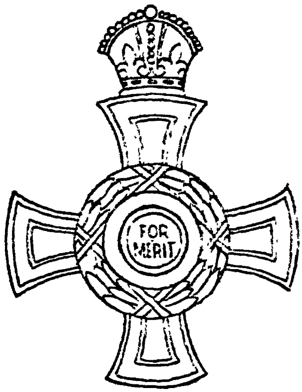
He had many invitations to lecture, and actually to his own surprise began to feel at home on the lecture platform. Great men from France and other parts of Europe crossed the Channel and came to Manchester to call on him.

All these things disturbed his life very little. His life hardly changed as the years passed. The British government gave him a small pension toward the end of his life. At first it was £150 a year, and then it was increased to £300. He must have been glad to have it. People in Manchester grew used to looking out of their windows and seeing him as he passed up the street with his broad Quaker hat, his white neckerchief, buckled shoes, and strong cane—tapping as he went along.

By the time they failed at last to see him, and the cane's tapping had stopped, John Dalton's atomic theory had become a part of the accepted world.

For more than fifty years after that, scientists worked on in the belief that they knew all there was to know about the stuff the world was made of. Gas, liquid, solid—it was all made of atoms, the little indivisible particles which John Dalton had described. All that the scientists had to do now was to study the way in which these atoms joined together and separated again. It was a secure, steady and comfortable world—this Victorian world of the late nineteenth century. It was good to feel that they knew all there was to know about what the world was made of.

But then, in 1907, Joseph J. Thomson, a man with drooping mustaches and a quiet manner, upset this comfortable world. He said that the atom was not the smallest possible particle of matter after all. This statement was to change the world for all of us.



13. The Revolutionary Ideas of J. J. Thomson

At Westminster Abbey in the year 1908, King Edward VII conferred the Order of Merit on some twenty people who had gained distinction for the Empire in military and naval affairs, in art, literature, and science. One Englishman to receive this distinction was Joseph J. Thomson, who had been a professor at Cambridge and at the Royal Institution in London, and who since reading a paper on "The Discharge of Electricity through Gases" at Princeton University in America had done further distinguished work on a new theory of matter.

The badge of the Order of Merit is a crest of red and blue enamel surmounted by an imperial crown. The central blue medallion bears the inscription "For Merit" in gold, and is surrounded by a wreath of laurel. The ribbon is garter blue and crimson, and is worn around the neck.

It is safe to assume that when the silken congregation saw

the badge with its red and blue ribbon they did not understand the service which the unpretentious man with drooping mustaches had performed. Great discoveries are very seldom understood by the world until long years after they have been made. Nor did the king who fastened the ribbon around the scientist's neck realize that the ideas which he was honoring were revolutionary in character: that they would change all scientific thinking, start hundreds of men on new researches, and end finally in a new world, the world of the atomic age. Yet all these things were true.

J. J. Thomson was fifty-two when he received the Order of Merit. There had been plenty of time in his life for work, and he had used it. He had been educated first at Owens College in England, and then he had won a scholarship for studying pure science at Cambridge University. The money for the scholarship had been raised, oddly enough, by the citizens of Manchester in honor of the great John Dalton.

Thomson had impressed the men under whom he worked: that was why, when he was only twenty-eight, he was chosen to be director of the Cavendish Laboratory of Experimental Physics, that great research laboratory at Cambridge, where important work in physics is still carried on today. To be head of the Cavendish Laboratory was one of the most honored positions in the whole scientific world. Many of the older scientists were a good deal upset by Thomson's appointment. What is the Cavendish Laboratory coming to? they said. A mere boy to be head of the Cavendish Laboratory!

But J. J. Thomson, though he was only twenty-eight, surrounded himself with brilliant associates and quietly went to work. His chosen field was the passage of electricity through

gases. He had been experimenting for a long time with Crookes tubes.

William Crookes, the son of an English tailor, had made the first tube of this kind some time before 1895. He had taken a section of glass tubing and sucked the air out of it with a vacuum pump. Then he had passed a high-voltage current of electricity through it, and a pale mysterious blue-green light appeared at the negative or cathode end of the tube. For want of a better name, the rays of light were called cathode rays. No one knew what they were. They behaved much like electricity, for they could be turned aside by a magnet. Yet they were a mystery, for to all intents and purposes there was nothing in the tube. How could nothing be electric?

It was with a Crookes tube then that Thomson and his associates were experimenting at the Cavendish Laboratory. They tried passing currents of varying intensity into the tube; they tried pumping more or less air out of it. Always the gleaming light appeared at the cathode end of the tube. They filled many notebooks with their careful records of the phenomenon.

It was on Friday evening, April 30, 1897, that J. J. Thomson announced that he had found the solution of the mysterious cathode rays. The solution came to him suddenly: that the atoms which, ever since Dalton's time everyone had believed to be indivisible, were not indivisible at all: they were not, therefore, the smallest imaginable bits of matter. The atoms themselves were capable of being divided. The light at the cathode end of the Crookes tube, he thought, was made of tiny bits of negative electricity that had been torn away from their atoms. They were tiny free particles, moving and dancing through space. Each atom in the world, he thought, might be

like this—a tiny fierce little world in itself, a world of moving parts.

It must have taken courage for J. J. Thomson to announce this idea, for it was indeed a very upsetting conception. Scientists since Dalton's time had believed that the atom was indivisible: they had thought that they knew all there was to know, on the subject of matter at least. Anyone who wanted them to believe that Dalton had not told the whole truth would certainly have to prove it to them. And how could J. J. Thomson prove such a thing as this? Atoms were too small even to see, much less to divide in pieces.

But J. J. Thomson, with his quiet voice and his studious manner, stuck to his idea.

> I regard the atom as containing a large number of smaller bodies [he wrote] which I will call corpuscles; these corpuscles are equal to each other . . . . In the normal atom this assemblage of corpuscles forms a system which is relatively neutral . . . electrification essentially involves the splitting up of the atom, getting free and becoming detached from the original atom.

The corpuscles he later called electrons, taking the term from the Greek word *elektron,* from which electricity also had derived its name. He thought of them as little specks of negative electricity which were spotted over the surface of the tiny mass of an atom. Under the influence of light or heat, they could be knocked away from the atom, and sent streaming along a wire, or whirling out through space.

J. J. Thomson imagined further that when an atom lost one or more of its electrons, or when it added one or more, it did not behave as it had done before; it was in fact different. And if the atoms that made up an element were different, then the element

itself must be different. So there could be any number of elements, not just ninety-two; and one element might be changed into another. It was strange how far reasoning along these paths might take you.

Of course it was all hypothetical: no one had ever seen an electron. That was why so many people thought the idea utter nonsense. Their incredulity made very little difference to J. J. Thomson and the men who worked with him. To them the electrons were as real as the pen and ink with which they made their records. Often they joined in a little group in J. J. Thomson's office after their work was over, comparing notes. Thomson was a stimulating director. He proposed problems, and his assistants worked like slaves to solve them. Now he asked: Could you make a camera that would photograph an electron? With great ingenuity C. T. R. Wilson succeeded in making such a camera. When he developed a plate on which the wavy crooked track of an electron appeared, they pored over it, marveling at the fact that he had photographed the tiny thing, yet not surprised that it was actually there. This they had known all the time.

Robert A. Millikan, one of J. J. Thomson's students, finally managed to see an electron, although he did not succeed in doing so until he had left the Cavendish Laboratory and gone to the University of Chicago. There in 1910 he performed his famous "oil drop experiment" and saw an electron, to which he had attached an infinitesimal drop of oil, floating down like a bright star in a tiny lighted chamber.

Ernest Rutherford, a young New Zealander who had come to the Cavendish Laboratory, watched all this work on electrons with great interest. It seemed to him that if the electron was a particle of negative electricity attached to an atom, then there

must be something positive to hold the atom together. He began to search for some proof that there was a positive particle at the heart of the atom. Apparently, if there was a positive particle, it was less active than an electron, harder to dislodge. You could knock electrons off their atoms by applying heat or electricity: you could not knock any positive particles off in this way. It would take something stronger than even the strongest electric currents or the hottest heat he could apply. To investigate the heart of an atom was the colossal task to which Ernest Rutherford now applied himself.

Rutherford was the right man to undertake this difficult job. He was filled with energy, and never seemed to rest. His friends said he could "arouse enthusiasm in anything short of a cow or a cabinet minister." He could "discuss any subject, smoke almost any kind of tobacco."

So the energetic Rutherford now set about trying to find out whether there were positive particles of electricity in the atom as well as negative ones. If he was to dislodge any such particles, he knew that he would have to knock them out with something stronger than electricity, something as swift as light. After various experiments he chose to use alpha particles, tiny particles of positive electricity which he had already identified. They possessed the greatest power of any particle known to science—seven million electron volts. These were the particles which were thrown off from such elements as uranium, radium, and polonium at the rate of twelve thousand miles a second. If any projectiles in the universe were capable of being shot into the heart of an atom, if any were strong enough to dislodge the inert positive particles, these should be the ones.

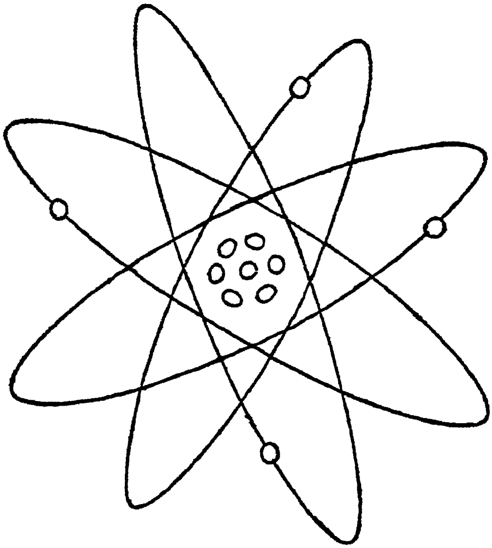
Rutherford worked patiently at his task. The First World

War came, and with the other men in the Cavendish Laboratory he gave his services to the government. But he found time to continue with his own experiments, trying to prove that there were particles of positive as well as of negative electricity in the atom. "If this is true," Bernard Jaffe quotes him as saying to a group of scientists who were waiting for his help on a submarine detector, "its ultimate importance is far greater than that of the world war."

Twenty-three years after J. J. Thomson's announcement of his theory of the electron, Rutherford was successful. With a very delicate and ingenious technique he had shot hundreds and hundreds of alpha particles at atoms of hydrogen. Most of them passed straight through the atom, but a few seemed to encounter something hard and swerve aside. With C. T. R. Wilson's camera he photographed the paths of the alpha particles. Most of the paths were straight, but here and there they were bent at an angle, as if the particle had hit something and turned aside.

This, then, was the hard particle of positive electricity at the heart of the atom, the hard central core. Rutherford named it proton.

Gradually Rutherford made a more complete picture of the atom in his mind. He thought of the electrons or particles of negative electricity circling around the central nucleus, as the planets circle around the sun. In this nucleus were not only particles of positive electricity, which he called protons, but also particles which were neither positive nor negative, which he called neutrons. The electrons went circling round the core of protons and neutrons like tiny planets circling the sun. Every piece of substantial matter in the universe, every drop of water,



every piece of rock, every bit of earth, every animal, every growing thing, every star, and the air itself—all were in reality a mass of tiny moving atoms. And each atom was a little solar system held together by the power of positive and negative electricity, perfectly balanced.

Solid matter was no longer solid. Every tiniest bit of it was a whirling mass of electrons, moving around central nuclei.

How many protons were there at the heart of each atom? Rutherford guessed that the number might bear some relation to the atomic weight by which Mendeleev had found the elements could be arranged in such orderly and revealing series. He encouraged Henry Gwyn-Jeffreys Moseley, a brilliant youth of twenty-six, to investigate. And Moseley, before he was killed by a Turkish bullet at Gallipoli, succeeded in the work he set out to do. He proved that the atomic weight of every element was in exact relation to the number of protons at its nucleus.

And now that J. J. Thomson, and Rutherford and Moseley

and others, had started things going, more and more hypotheses and more and more discoveries were to follow. Niels Bohr in Copenhagen thought the electrons moved around the central nucleus in regular elliptical orbits. From time to time, in a kind of spurt, an electron jumped over into another orbit, like a horse jumping over a hedge into another race track. When this happened, he said, energy was released from the atom.

Irving Langmuir of the General Electric Company in Schenectady thought that each atom was trying to complete an outside shell of electrons. When it added or lost an electron from this outer shell, it changed its properties.

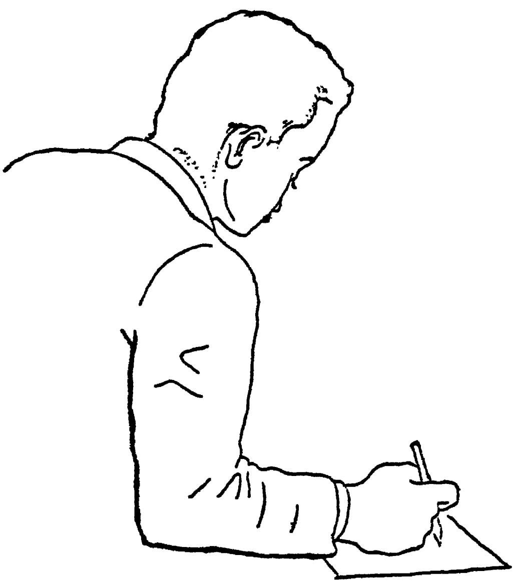
Ernest Orlando Lawrence of the University of California discovered a way to make a 4,900-ton, 300-million volt cyclotron, which could whirl the sluggish particles with such force and speed that one element might change to another.

While all this work was going on in the laboratories of the pure scientists, the electrons were being put to practical use. Just as current electricity had once been made to convey messages along telegraph wires, or to light lights, and electricity and magnetism had been used to generate power for great motors, so now industrialists were doing research in what they called electronics. A. J. Fleming, working with Edison, had discovered that electrons were especially active in a vacuum, and Lee De Forest, experimenting in New York, had made the first real radio tubes, some of them no bigger than a thimble, some taller than a man. Now men were finding a hundred ways of using electronics—to open and close doors, to sort colors, to test the structure of metals, in radio and television, to operate the extraordinary electron microscope, to reach the moon by radar, to work calculating machines with the speed of magic.

But while all these things were going on, the scientists in their laboratories worked on, seemingly oblivious, and more and more startling were the discoveries they made. Enrico Fermi, who was working at Columbia University, announced that the capture of a particle of only one-thirtieth of a volt could release from a uranium atom's nucleus 200,000,000 volts of energy, and that he said was more than six billion times the energy shot into it.

Fermi saw no cause for alarm in this discovery. He was not even sure whether his discovery would have any practical consequences at all. Practical consequences were not his concern at that time, for he was working in the field of pure science.

J. J. Thomson's theory as to the structure of the atom had indeed taken the scientists on a long undertaking in their search for truth. And meantime Albert Einstein was making some startling conclusions. He conceived the idea that mass and energy were interchangeable—a strange enough idea, when you come to think of it.



14. *The Cosmic Trinity*

In the Patent Office in Switzerland where he was employed, the young Albert Einstein did not really have enough to do. He could complete the work assigned him in about four hours. What then should he do with the four hours that remained?

He might have spent those four hours moping and dreaming —working slowly, sandwiching the dreams between the patents. He might have remembered the day when he was still quite a little boy and his father had brought him home a compass. How he had wondered at the quivering needle that always stubbornly pointed toward the north, no matter how he turned the compass around.

He might have been dreaming of his violin—the strange power of the music that he could draw from it with his strong quick fingers. Or in another mood he might have brooded on the fact that he was a Jew, remembering the mockery to which the children in his school had subjected him, or how he had tried to find employment after he had graduated from Zurich Polytechnic Institute, and been often rejected because he was a Jew.

But Albert Einstein spent none of his precious time on matters such as these. He worked quickly and on the desk before him, after his work on the patent applications was done, he placed a sheet of paper. Bending over it, he wrote equation after equation with the stub of a worn-down lead pencil. Whenever the footsteps of his employer, Dr. Halle, approached, he slid the paper with its equations into a drawer and pulled a patent application toward him. When Dr. Halle departed, he drew the mathematical equations out again.

He was very happy as he sat at his desk in the Patent Office, for he was exploring new territory, finding new truths that no man had ever even imagined before.

"I have been trying to solve the problem of time and space," he told his young Serbian wife one evening when he came home from the office. Time and space, and the relationships that were between them: space, and the matter with which it seemed to be filled: the stuff the world was made of—these were the substance of his formulas, the occupation of his restless mind.

It appeared to him, when he considered it, that everything in the universe was moving—for a universe in which everything tended to stop would soon be a cold, dead universe. Motion,

not rest, he thought, was the natural condition of all things: a stable earth was an "illusion." All things were forever moving. In the tiniest atom, and in the greatest of the galaxies, there was motion.

Of course it was difficult to detect or measure this motion, since the observer himself was always moving too. The direction in which any object moved, and the speed of its motion, depended on how fast and in what direction the observer was moving himself. It was a relative matter.

And just as the speed and direction of a moving body are relative to the observer, so the size of a moving body is also relative, since every object appears to contract with motion, and the rate of contraction increases with mounting speed. More than this, it seemed to him that time, like space, was a relative thing: if a man could move faster than light, he would overtake himself and arrive in the future. That would be impossible, of course, since nothing in the universe can move faster than the 186,000 miles a second which is the speed of light.

The young Einstein worked out formula after formula to prove these strange and hitherto unimagined facts—formula after formula—the sheet of paper disappearing into the drawer when Dr. Halle approached.

After Einstein had worked out the relationships of time and space to his own satisfaction, he copied the formulas carefully, with a brief explanation. His work covered thirty closely written pages. He carried these papers to the editor of the *Annalen der Physik.*

"If you should have space in your journal to publish this, I would be much obliged," he said. Then, worn out and exhausted

with his work, he went home to bed and stayed there, weak and sick, for nearly two weeks.

The editor found space to publish his paper. It was thus that the theory of relativity was born. Einstein called his paper "Toward the Electrodynamics of Moving Bodies." In June 1905, when it was published, he was twenty-six years old.

The theory of relativity caused a great hubbub. Its author, pushing the perambulator that held his first baby, was rather amused at it all. Still, honors were soon succeeding one another for him. He was offered a professorship at the conservative old University of Zurich, and then another and more remunerative post at the University of Prague. He stayed at Prague for a year and a half, living as simply and as quietly as he had done when he was a clerk in the Swiss Patent Office. When he was not working, he walked about the Czech city, wandering often into the old Jewish cemetery there. "A singular, taciturn, lonely seeker," people called him.

"I think and think for months and years," he said when he was in Prague. "Ninety-nine times the conclusion is false. The hundredth time, I am right."

In 1912 he returned to Zurich again to lecture at the Confederate Polytechnic Academy, where he had studied as an undergraduate. But he was timid in the lectures he gave there, as he had been at Prague: he described them as "performances on the trapeze."

So he was glad when an invitation came to leave his teaching and go to Berlin. There at the Prussian Academy of Sciences, that great institution founded by Frederick I of Prussia, no fixed duties were required of him. He could work at his own pace and as he wished. He was also made a director of the

Kaiser Wilhelm Institute for Research, and managed to make a formal address to the gray-bearded and distinguished scholars who were its members.

Einstein was thirty now. He and his first wife had agreed to a divorce and he had married again. Elsa Einstein, his second wife, was a distant cousin: a competent, cheerful, and sensible companion. They had an apartment on Haberlandstrasse in Berlin, with yellow flowered wallpaper in the sitting room, family pictures on the walls together with a portrait of Frederick the Great with two dogs, and a grand piano in the bare room that was his study. He generally played his violin in the kitchen, though, saying the acoustics were better there. It seemed as if Albert and Elsa Einstein would live out their lives peacefully in Berlin. But then the First World War came.

Einstein recoiled from the idea of war. While the tramp of soldiers' feet broke the silence of his barren study, he continued his work. "Working is thinking," he said. He finished his General Theory of Relativity, while his neighbors suspected him because of his pacifist beliefs. He was working on the size and shape of the cosmos.

"It is impossible that a straight line is the shortest distance between two points," he once said. "There are no straight lines in the universe. Everything is moving in curves. It is possible to calculate the curves and so measure the size and shape of the cosmos. Therefore space is no longer infinite."

It happened that in 1919 there was an eclipse of the sun. The English astronomers from Greenwich and Cambridge sent expeditions to Brazil to photograph the direction of the starlight during this eclipse. The photograph, which they later sent to Einstein, proved that his calculation was correct to the last decimal

point. The rays of light from the stars curved toward the sun as he had said they would. The universe was a curved universe.

One of the greatest distinctions a scientist can attain is the Nobel Prize. Alfred Nobel, the third son of a distinguished Swedish family, had made a vast fortune by the invention of dynamite. Eight million dollars of this fortune he set aside in a fund, the interest of which was given each year to the men who made the greatest advances in physics, chemistry, medicine, literature, and the increase of good will among nations.

In 1921 Einstein was given the Nobel Prize in Physics. He gave away the money, for it seemed to him that money was of little worth. He had once said, "I am absolutely convinced that no wealth in the world can help humanity forward. The example of great and fine personalities is the only thing that can lead us to fine ideas and noble deeds. Can you imagine Moses, Jesus or Gandhi armed with the money bags of Carnegie?"

If he rejected the money which his fame brought with it, he could use fame in another way, however. Now that World War One was over, he decided to make a series of "good will tours"—to talk from public platforms against a new outbreak of war. And there was another cause as near to his heart as this: the cause of Zionism. He would speak in behalf of the persecuted Jews.

Now he began a long pilgrimage, taking his violin with him to compensate in his private hours for the misery the public lecture platform always brought. He went to England, to France and Spain; to Latin America, to Japan where the Empress took him to the Feast of the Chrysanthemums in the palace garden; to India where he pitied the Hindus who looked like "nobles changed into beggars."

Everywhere he went he talked of pacifism and disarmament and the Jews, not like a great scientist, but like a great human being. "It is plain that we exist for our fellow men—in the first place for those upon whose smiles and welfare all our happiness depends, and next for all those unknown to us personally but to whose destinies we are bound by the tie of sympathy. . . . I am convinced that, left alone, people would not hate each other. . . ."

In 1933 Einstein visited America, and saw the Mount Wilson Observatory in California, and talked with the physicist Robert A. Millikan. But all the while he was traveling and talking, Hitler and the Nazis were establishing themselves in Germany. The Reichstag fire occurred while he was on his way back to Berlin from the United States, and the general election of March 5, 1933, gave Hitler absolute power.

The news of the Nazis' triumph in Germany came to Einstein on shipboard, whither Hitler telegraphed to the great German scientist that "he would overlook the fact that he was a Jew." This message angered Einstein. He changed his plans, landed in Holland instead of Germany. His refusal to return to Germany enraged the Nazis; they looted his house, his securities were confiscated by the state, and the University of Berlin accepted his resignation "without regret."

The planets whose courses Einstein had measured and charted were still swinging round in their appointed places, but the world of which he was a part seemed to be collapsing. His friends persuaded him to take temporary refuge in Holland.

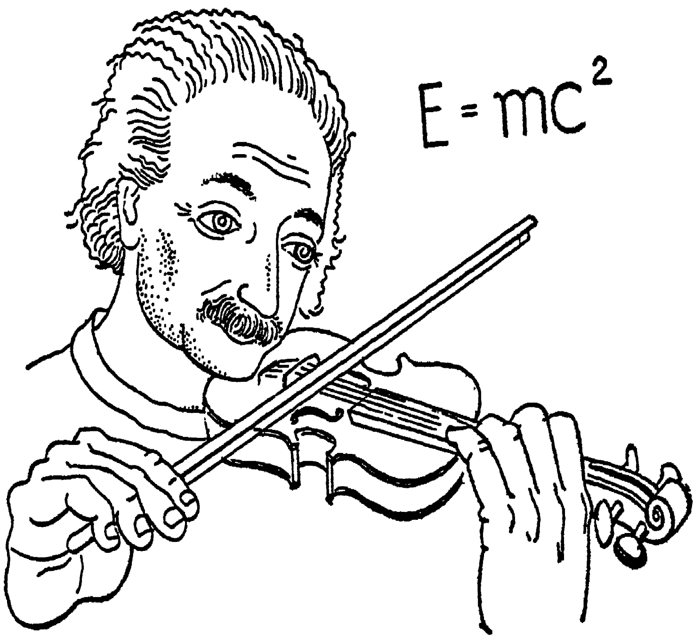
In the autumn of 1933, the Institute for Advanced Study at Princeton, New Jersey, offered Albert Einstein a post. He and Elsa came back to America and took a little white house on

Mercer Street in Princeton. Every day he walked along the maple-shaded streets to the meadow where the big new building of the Institute stood. Elsa died in December 1936, but he lived on in the little house. Every morning the neighbors saw him, his silvery hair waving in the sun, or blowing in the rain, as he walked to his study accompanied by some young student and by his dog. In the evenings they could hear him playing his violin.

And in his office in the big new Institute building, Albert Einstein, an American citizen now, continued with his work. His general Theory of Relativity had worked out a scheme for understanding time and space. Now he was trying to fit his theories of matter and electricity into that scheme. If mass and energy were the same thing, as he had proved in 1905, could one be converted into the other? Was an atom made of moving particles, as scientists had assumed? Or were the particles nothing more than movement itself?

Once again, as he had done so long ago in the Swiss Patent Office, he expressed his staggering conclusions in terms of a simple mathematical formula. $E = mc^2$, he wrote. "E" represented energy, "m" stood for mass, and "c" the speed of light. The formula has been interpreted to mean "Every pound of any kind of matter contains as much energy as is given off by the explosion of fourteen million tons of TNT." Every particle of matter may be measured in terms of the energy that races through the universe at the rate of 186,000 miles a second. So very small amounts of matter contained enormous amounts of energy: then a piece of coal the size of a pea (according to Einstein's equation) contained enough energy to drive an ocean liner across the Atlantic and back.

What could men do if such amounts of energy could be released from the matter which held it? How could it be used? Already, while Einstein was working on his formulas in Princeton, men and women in many laboratories were trying to release the forces that the atoms of matter held. While most men were going on their way, earning their bread and eating it, a new age was being born.



15. *Like the Light of Many Suns*

Lise Meitner need not have left Berlin. It was true that anyone not strictly of Aryan blood was in some danger, and Lise Meitner's mother had been a Jew. But she herself was a Lutheran, and her work at the Kaiser Wilhelm Institute was highly respected. There seemed to be little danger for her personal safety. Still, there were rumors that disturbed her: she decided finally that she must go.

"I heard there was to be a law forbidding all teachers to leave Germany. I wanted to continue my work, so I left. There was no trouble."

She had spent most of her sixty-seven years working in physics laboratories. Gray-haired, slight and rather delicate-looking, her friends thought her retiring and frail. But when it came to a question of her work, she was as strong as the next one, stronger perhaps. She put away her apparatus at the Kaiser Wilhelm Institute, closed her door behind her, and started on her journey to Sweden.

When she decided to leave Berlin and go to Sweden, the work which she and her associate, Dr. Otto Hahn, had done at the Kaiser Wilhelm Institute was not altogether complete.

They had found a way of bombarding atoms of uranium with neutrons, and had discovered that when they did this, the uranium was changed into barium. They did not know exactly why. Further investigation made them believe that the uranium atoms had been split in two. The process came to be called "nuclear fission."

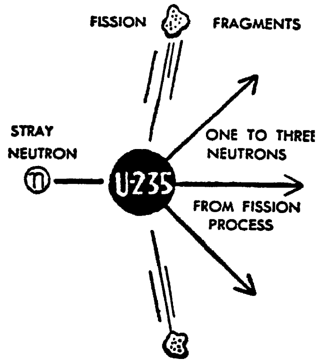
The extraordinary thing about their work was not so much that they had split atoms in two, though this was remarkable enough. But when they weighed the two fragments of a split atom, the combined weight of the two fragments was less than the atom had weighed in the beginning—about six per cent less. Here was a strange thing. Why did it weigh less?

It was not until she had reached Sweden, and had spent many hours in mathematical calculation, that Lise Meitner understood the significance of this. She proved now that the bombarding neutrons had penetrated the nucleus of the uranium atom, that the neutrons in this atom had been liberated and moved with such enormous force that the part of their mass was converted into energy. She had long known Einstein's formula $E = mc^2$. Now she could see that the energy which her slender fingers had unleashed, the energy which was six billion times stronger than the bombarding neutron had possessed, was created through the interaction of Einstein's cosmic trinity. Here was a power stronger than anything that men on earth had ever known before.

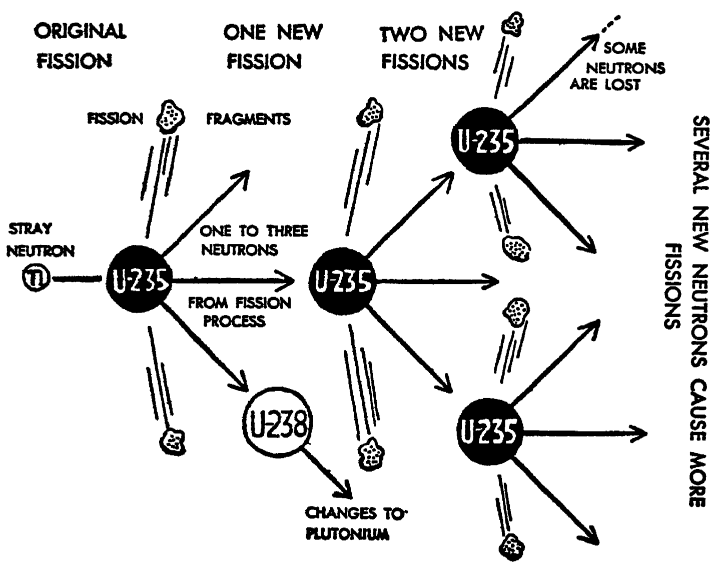
Lise Meitner took her carefully worked equations to Niels Bohr, the great atomic physicist who was working at Copenhagen. Together they considered the extraordinary force that had been produced by splitting the uranium atom.

Niels Bohr came to America later in 1939. At Columbia

University he talked with Enrico Fermi, who had escaped from Mussolini and found refuge in the United States. As they talked, it appeared to them that when the uranium atom was broken into fragments, additional neutrons might have been released from it in some such way as shown in the picture at the right.



Fermi thought that if this was the case, the released neutrons might be controlled, and made to pierce other atoms; that it might be possible to set up a whole chain of explosions one after another, each one releasing more energy than the last, something like this:



On January 26, 1939, there was a meeting of theoretical physicists in Washington. At this meeting Fermi told of his guess that a chain reaction might be possible. It was only a guess, but the idea so captured the imagination of the scientists who heard Fermi talk that before the year was out as many as a hundred scientific papers had been written on the subject. And experiments were under way, not only at Columbia where Fermi worked, but at the Carnegie Institution in Washington, at Johns Hopkins, and at the University of California.

Meantime, outside the quiet laboratories where the scientists worked, war was moving across the earth. Hitler had overrun Czechoslovakia in March of 1939, and Franco had entered Madrid; in May of that year Germany and Italy had formed a military alliance; and in September Germany bombed and invaded Poland. In April 1940 the Nazis moved into Denmark and Norway, and then on into Holland, Belgium, and France.

As the armies rolled on across Europe, those who were not in sympathy with the Fascist philosophy were imprisoned or killed. But some managed to escape and a number of them found refuge in the United States. Among these refugees were some of the greatest scientific thinkers of the century: Dr. Leo Szilard and Professor Eugene Wigner, Professors H. A. Bethe and E. Teller and V. F. Weisskopf, and Niels Bohr who had slipped away from Denmark in a small open boat. The United States was vastly stronger because of their coming—although in 1940 hardly anyone realized that this was true.

Among all the scientists, nuclear fission was of enormous interest. Could the energy released from the heart of the atom be multiplied and controlled and used? To the American scientists, immersed in their experiments, the question of a possible

chain reaction was still a theoretical one; to them the war still seemed unreal and far away. But to the refugees who had escaped from Europe, who knew of the concentration camps, the forced labor, and the moving armies, it was another thing. Unless the United States was prepared, it might be only a matter of time before New York, Philadelphia, and Boston had gone the way of Cracow and Rotterdam.

Still Hitler's armies moved on. The danger came closer to the United States. And now the scientists made another effort. They decided to approach President Roosevelt himself. Albert Einstein wrote a letter to the President. It was carried to Washington by Alexander Sachs. A conference at the President's office was arranged.

Franklin Roosevelt was impressed with Einstein's letter, and with the urgent pleas of the other scientists. He had enough imagination and enough courage to try the hitherto untried. He appointed the now famous "Advisory Committee on Uranium." The committee's first report to the President was made on October 21, 1939.

It would be possible to prepare an atomic bomb whose almost limitless power was derived from splitting uranium atoms, they reported. The preparation of such a bomb would normally take years of experiment, the work of thousands of men, the expenditure of an unknown amount of money. Given these things, physicists agreed that a chain reaction was theoretically possible, but they had never actually brought such a reaction about.

So it was that Roosevelt and his advisers made their decision, and gave the word to go ahead. We had indeed money and men enough. It might be that we had very little time.

The chain reaction could be best accomplished by using uranium, the scientists said. But there was little or no uranium in the United States in 1940. The metal does not occur in a pure state: it is always combined with radium or some other metal in an ore. Some ore bearing uranium was known to exist in Colorado, and it was to be found also in the Great Bear Lake region of Canada, in Joachimsthal in Czechoslovakia, and in the Belgian Congo. It was not known how much of the ore it was necessary to import, how long it would take to separate a sufficient amount to use, exactly how this should be done, how dangerous the work might be, or how much it would cost. After the uranium had been separated, the method of bombarding it with neutrons must be studied, the energy generated must be controlled.

Almost from the beginning Nazi spies were trying to find out how the work was being done. The Nazis themselves at the Kaiser Wilhelm Institute in Berlin were working to develop an atomic bomb, it was reported. No one knew how nearly they had brought their work to completion.

Speed was the prime requisite—speed and secrecy. Provision must also be made against the dangerous emanations that might hurt those who were doing the work. A new personnel must be found and trained. But, above all, the work must be done in secret.

On December 7, 1941, the Japanese bombed the American fleet at Pearl Harbor, and on the 8th the United States declared war on Japan. A few tense days passed, and on December 11th Germany and Italy declared war on the United States.

The work on the atomic bomb went on. At Oak Ridge, Tennessee, a whole city had been built. Every man employed

in that city knew that he was working on an important government project: no one knew exactly how his part of the work fitted into the general scheme.

At Hanford, on the west side of the Columbia River, in the State of Washington, another city housed thousands of workers employed on the great project.

No one knows exactly what work was done in those strange new cities, nor in the many laboratories where experiment on the so-called Manhattan Project was carried on at feverish pitch. In none of the places where the work was done did anyone ever say the word bomb. If it was necessary to speak of it at all, they called it "Zero." By November 1942 a site had been selected in New Mexico for the actual manufacturing of the bomb. Four months later J. R. Oppenheimer, who was to be in charge of it, together with a small group of other scientists and military experts, traveled up the winding mountain road to the lonely plateau where the plant had been built. Then three carloads of apparatus were brought from Princeton, a cyclotron from Harvard, generators from Wisconsin, and a high-voltage device from Illinois. In the loneliness of the New Mexican desert, the work of making the bomb began.

Franklin Roosevelt died on April 12, 1945. And Germany made an unconditional surrender to the Allied Armies on May 7th of that year. But the war with Japan continued.

By July 16, 1945, the work on the bomb was finished. Just before dawn on that day, about fifty miles across the arid plain at Alamogordo, New Mexico, the new bomb was raised on a tower of structural steel a hundred feet high, and a complicated set of automatic controls was attached to it. A group of eminent scientists had traveled up to the plateau in the night and sat

waiting in the coolness for the dawn. It was misty, and occasional flashes of lightning flared across the sky.

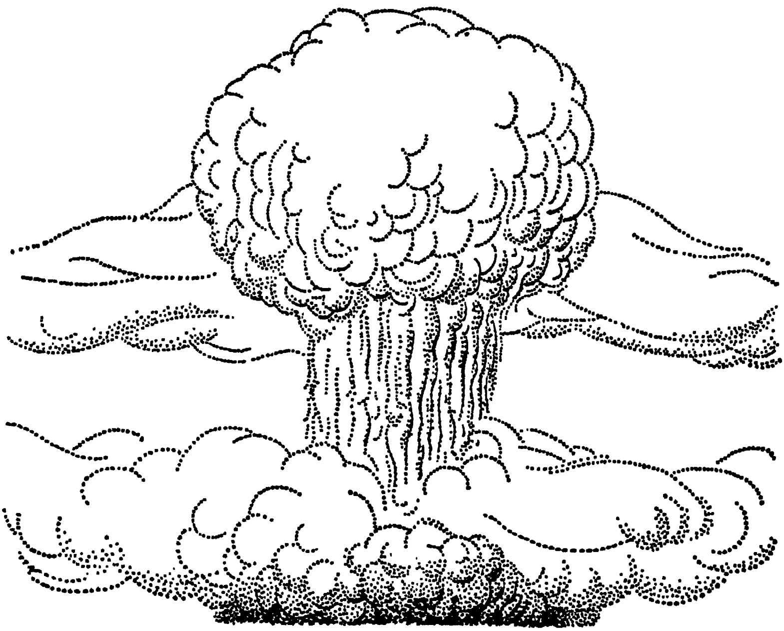
The scientists had stationed themselves about twenty miles from the scaffolding that held the bomb, and waited while the minutes ticked themselves away. Five-thirty was to be the "Zero" hour: the hour at which the energy locked in the heart of the atom was to be set free for the first time in history. Finally a siren sounded. It was understood to mean "All personnel whose duties did not specifically require otherwise" were to prepare "a suitable place to lie down."

Another long signal sounded at minus two minutes to Zero. "All personnel whose duties did not specifically require otherwise" were to "lie prone on the ground immediately, the face and eyes directed toward the ground and with the head away from Zero."

"Do not watch for the flash directly," the order read. "But turn over after it has occurred and watch the cloud. Stay on the ground until the blast wave has passed (two minutes)."

So the hands of the clock moved on. It was one minute to Zero; it was thirty seconds; fifteen seconds—the Zero hour had come.

Then to those watching in the early morning of the New Mexican desert, there was a light—not like any light that had ever been seen on earth—a light like the light of many suns. And up from the earth went rushing a great green mushroom cloud. It rose to a height of eight thousand feet, touched the morning clouds with its brilliance, lighting all the earth. Up and up the cloud kept moving, changing its colors from green to yellow to red. From the top of the mushroom a new pillar of fire rushed upward, and mushroomed again. Higher and



higher it moved through the many-colored clouds, until it had disappeared at last into some far corner of the universe.

The men on the ground stood up. They had seen a thing which no man in earth's history had ever seen before.

In August 1945 atomic bombs were dropped at Hiroshima and at Nagasaki. Their terrible devastation brought the Second World War to a close.

Some Americans were aghast at the destruction they had wrought, and terrified at the power they had learned to wield. Some talked of the new world they would develop with the power that could be torn from the atom's nucleus.

PART III

How They Studied the Cosmic Fire

Light through a chink
Falling serenely
On a cottage wall.
The prism and the broken light,
The spectrum and its radiant colors.

The labor of many men
Working to find
New waves of light
No human eye can see.

The waves and waves
Of radiant energy that move
Through all the universe
With speed like light.

The cosmic fire.
The unanswered questions.
The unfinished task.

16. *Light through a Chink*

The young Isaac Newton was making himself a kite with sticks and cloth. He fastened a tail to it of knotted rags, and attached a very long string. When it was dark, he took it to a field outside the English village where he lived, fastened a little light to the tail of the kite, and ran across the field, trying to raise it into the air. Maybe the shepherds in their thatched cottages would think a new star had come into the sky. He laughed to himself to think how they would believe they had seen a sign, a token maybe that the end of the world was near.

But though he tried again and again, Isaac Newton could not fly his kite with the little light. The lantern was too heavy,

and he had to give it up at last. The neighbors heard of his experiments. "Fool us, would he?" they said, and they laughed. "Him, always mooning around with lights. Making windmills and water wheels, and driving pegs into the side of a wall to measure how the sun's shadow marks the time. It would be better if he would study what the teacher tells him."

It was true, Isaac Newton wrote it in his own journal later —he was lowest in the lowest class but one of the village school at Skillington. Yet the boy, who seemed dull and inert to his masters, and who was scorned by the other pupils of his school, was to tower head and shoulders above the scientists of his age. The stone with the peg driven into it, which he had used for a sundial, was to be preserved as one of the chief treasures of the Royal Society in London. You can see it in the library of that dignified Society still; the letters WTON, roughly carved, may still be discerned on it. The N and the E have disappeared.

Isaac Newton was born on Christmas Day in 1642: 1642 was the year in which Galileo died. His father, a farmer, died before he was born, and his mother, "an extraordinarily good woman," married a country minister two years later. So Isaac went to live with his grandmother, and went to the village school with rather poor success, although whether he himself was content with the work he did on the sundials and windmills we have no way of knowing. We do know that he made a water clock that went quite well as long as he was in the neighborhood to regulate it.

In 1658, the night that Oliver Cromwell died, there was a great storm in England, with a terrific roaring wind. It has been recorded in history as one of the worst winds the island ever experienced. Isaac Newton, who was then sixteen, was

fascinated at that time with trying to measure wind velocity and he made the best of his opportunity in the storm. He went out when the wind was blowing at its height; he jumped with the wind, marking the place in which his feet landed; he turned and jumped against the wind, marking again. Neighbors, hurrying to get in out of the wet, to fasten their shutters and bolt their doors, must have thought him a little mad.

His education did not end with the village school. He was sent away to a grammar school at Grantham, where he boarded with a druggist, but again he did not distinguish himself. Soon he was home again, learning, it was said, to be a farmer. But he was always borrowing scientific books from those who had them, making mechanical contraptions, wondering what the sunlight was made of.

One day, when he should have gone to market with lambs and eggs and other farm products to sell, it was found that he had sent a hired hand to do the business, while he lay under a hedge, reading a book on mathematics. When he was discovered under the hedge there was a family crisis. What should be done with a boy like Isaac Newton? While the family fumed, an uncle gave the solution. Send him to college, he said, where he can have his fill of mathematics. So Isaac Newton left his farming, and went to Cambridge.

Mathematics absorbed him completely at Cambridge. In his first year he worked out the binomial theorem and the whole theory of differential calculus. He figured and checked his results; he generalized his findings, and wrote down the principles he deduced. He did not tell anyone about his work; it did not seem to him necessary.

It was while he was still in his first year at Trinity College,

Cambridge, that Newton noticed some halos around the moon, and began to measure them. Then he wrote in his notebook:

> Small colored halos around the moon are often seen, and said to be a sign of rain. They are produced by the action of minute globules of water or cloud particles upon light.

So his work at Cambridge continued, and in 1668 he was given the A.B. degree. And now it seemed to him that he was only at the beginning of his work. He returned to the University as instructor in mathematics the next year, and continued his studies.

But his work at Cambridge came to a sudden pause, for the plague broke out in London and before long it had spread to Cambridge. Soon the University was closed: every student and instructor was sent home. Isaac Newton too, went home to Lincolnshire, his mind seething with ideas.

It was during this year of the plague, and before he was twenty-five years old, that practically all the foundations of Isaac Newton's great work were laid. Here in the country, without interruption or disturbance, he thought and worked, not content to theorize and guess—wanting to prove mathematically each step to which his bold imagination led him.

He wanted to know what made the planets revolve around the sun. With excitement and rapture, he conceived the idea of gravity, and with exact mathematical calculations, laid the foundations for the great work which was later to be published as the *Principia.*

But although Newton's work on the laws of gravity is the work which has won him his great fame, his work on light is equally important. It is this which concerns us here. As a little

boy he had tried to invent new stars by fastening lanterns to the tails of kites; then he had studied the movement of the stars and sun, and finally, in that year before he was twenty-five, he began to study the light itself—the light of flames, the light of stars, the light of sun and moon. He was fascinated by the shine of them. Careless of his dress, heedless of food, uninterested in human society, he worked for hours together to understand how light behaved. A little account book which he kept has been carefully preserved. In it he wrote down the expenses he incurred in his work: they were almost entirely for lenses, prisms, polishing powders.

Newton had read of the work of Galileo, and knew of the telescope Galileo had made, by which rays of light could be bent by passing through a lens, until objects appeared much larger than they do through the lens of the eye. Newton, with his passion for mathematics, figured out the angles of the rays of light, and succeeded in making a telescope with a lens in which the light was reflected back from a mirror. This telescope was only one inch in diameter, and six inches long, but it magnified forty times the object he looked at. One night he set it up in his window, and beheld the satellites of Jupiter.

A solitary, quiet young man, with keen eyes and a homely face, few people paid any attention to him. It was the custom in his time for any scientist who made a new discovery to write a paper on it and to have it published. But Newton never thought of publishing his work. He was too busy making new discoveries to stop and talk about what had already been done.

Nevertheless his reputation as a mathematician grew in a quiet way. And Isaac Barrow, a friend who was a professor at

Cambridge, proposed that he should be elected a fellow of the Royal Society. In the seventeenth century, when the mass of scientific knowledge was smaller than it is now, it was a common thing for groups of men, who called themselves philosophers, or lovers of wisdom, to come together to discuss experiments they had made. So in London the members of the Society met regularly together to discuss such questions as how much air a man's lungs would hold, how fast sound traveled, "whether there be any such thing as sexes in trees and plants." Christopher Wren, the architect of St. Paul's in London, was one member of this group; Robert Boyle another, Many people made fun of the experiments of this group. Some of them disapproved on religious grounds, objecting to "Natural Philosophy as a carnal knowledge, and too much minding worldly things." But Charles II gave a charter to the Royal Society in 1660, and often came to their meetings, although Samuel Pepys said that he "mightily laughed at them, for spending time only in weighing air, and doing nothing else since they sat."

But though it was the fashion to laugh at the Royal Society, there was no other meeting ground for the scientifically minded in London. So, under the insistent persuasion of Isaac Barrow, Newton allowed his name to be proposed for membership in this Society: he sent them a telescope which he had made. That telescope may still be seen in the rooms of the Royal Society in London today. The inscription on it reads:

> The first reflecting telescope, invented by Sir Isaac Newton, and made with his own hands.

The members of the Royal Society were greatly interested in Isaac Newton's telescope. It was the best one that had ever

been made up to that time. They instructed their secretary to write him a special letter of thanks.

Newton was much surprised to receive the secretary's letter. The gift of the telescope had not seemed to him a very important affair. However, he acknowledged the letter and offered to send them an account of some researches he had made, "being in my judgment," he wrote, "the oddest, if not the most considerable detection that has recently been made on the nature of white light."

Now the world was to know of his researches. Now he was to tell them what he had discovered with his lenses and prisms in the lonely room where he worked.

In working on the lens of his telescope he became much interested in the behavior of light rays, and decided in time to try the light through a prism. He made a round hole in the shutter of a darkened room. He inserted a prism in the hole, and let the sunlight shine through. There on the opposite wall he saw a long band of light—not white light, but colored with the colors of the rainbow. Violet, indigo, blue, green, yellow, orange, and red, he named them.

He tried another prism: the result was the same.

It seemed to him, then, that the rays of light that the sun poured down through the hole in his shutter were not all alike: that they were not all bent in the same way in passing through the prism. Could it be that the white light was not one substance, that it was a mixture of the rays of many colors?

With ingenious and patient experiment he succeeded in passing the colored light through another prism, and recombining the rays into white light. This was "the oddest, if not the most considerable detection"—that white light was not really white

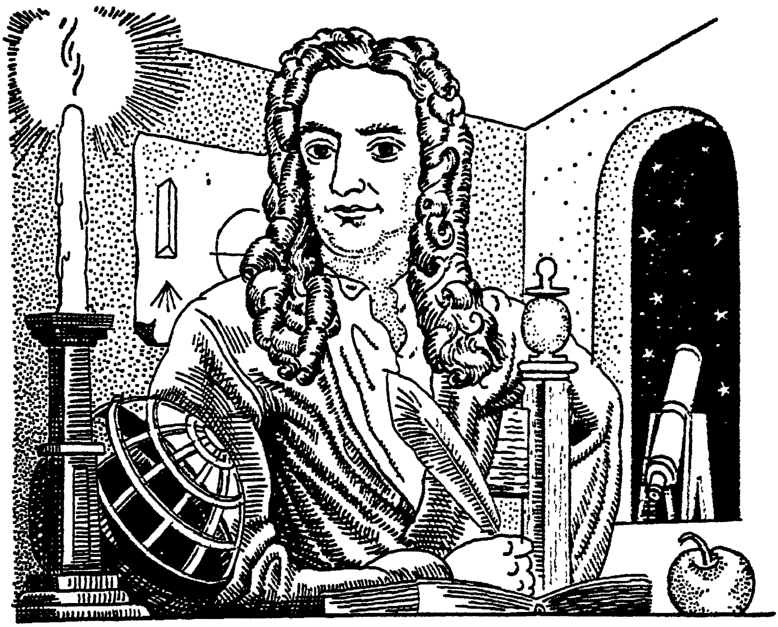
light at all: that it was a mixture of violet, indigo, blue, green, yellow, orange, and red.

Newton was made a fellow of the Royal Society in 1672, and they published his findings on light, though some objected that what he said was not proved. But he paid little heed to them. By that time he was working again at the theory of gravity, proving with new mathematical data that his earlier conceptions were right. The discussions of other scientists, questions of prestige, rivalries and arguments, were nothing to him. Sometimes a friend came to see him, and he went off to buy a bottle of wine and forgot to come back again. Once a Dr. Stukeley came to supper. Newton was not in when Dr. Stukeley came. A roasted chicken lay in a covered dish on the table. An hour passed, then another, but Newton did not return. The friend decided to eat the chicken, leaving the bones in the covered dish. Isaac Newton finally returned, lifted the lid: "I thought I hadn't eaten my supper," he said, "but it seems I have." Putting down the lid again, he embarked on a long scientific discussion.

Stories like those went the rounds in London. It did not matter to him. He went on with his work. His niece came to live with him and take care of him, but his habits did not change.

"A great man, Isaac Newton," people were saying. They made him a member of Parliament, and he was knighted—he was Sir Isaac Newton now. He was elected president of the Royal Society. But these things did not matter very much to him: his life was in his work.

Once, toward the end of his life, his dog Diamond tipped over a candlestick, and papers with mathematical calculations accumulated over many years were burned. He brooded over



this. It appeared as if all his work and his brooding unsettled his mind. A letter has been preserved which he wrote to Samuel Pepys, and from this letter he appears to have become mentally unsound.

But he improved again: he lived on. Someone asked him how he made his discoveries. "By always thinking unto them," he said. "I keep the subject constantly before me, and wait till the first dawnings open slowly by little unto a full and clear light."

Yet even at the end of his life he did not feel that he had accomplished any great thing. He wrote:

I do not know what I may seem to the world, but as to myself, I seem to have been only as a boy playing on the seashore diverting

myself in now and then finding a smoother pebble or a prettier shell than ordinary, while the great ocean of truth lay all undiscovered before me.

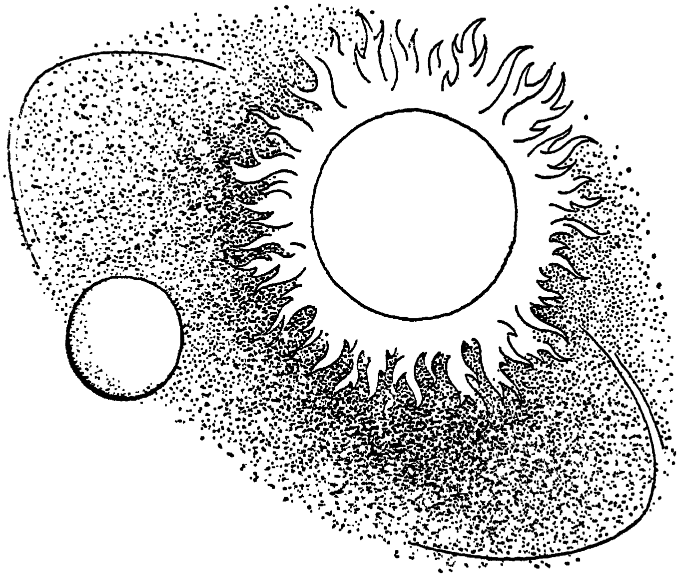
Great scientist though he was, there was indeed an ocean of truth which others must explore. For he did not really know what the light was that he had seen in the chink through his shutter. He thought that every luminous body threw out little particles or corpuscles which hit against his eyeball. Many men disagreed with this notion, but so great was his reputation that very few dared to say so aloud. Among the brave few who disagreed with his "corpuscular theory" was the poet Goethe in Germany. And Benjamin Franklin in America also dared to disagree. But if there were others, not much is known of them.

There was, however, one man, Christian Huygens, a Dutchman, who dared to propose another theory as to what made light. Huygens was an astronomer and a designer of telescopes, and he worked at the court of Louis XIV. It seemed to him that light was an ever-advancing wave from which smaller waves spread out. Isaac Newton objected strongly to the idea of light waves. He wrote, "To me the fundamental supposition itself seems impossible. . . . I mistake if there be not both experiment and demonstration to the contrary."

No one up to the present time knows what light is. As time passed, Newton's corpuscular theory was abandoned, and scientists thought they found more and more proof that Huygens's wave theory was right. Gradually they were able to measure the light of the stars and the sun, to calculate the speed of light that comes piercing through space. In the work that expressed their "eternal longing for understanding" they found that light was related to heat and magnetism and electricity. But in the

twentieth century the scientists began to question the wave theory too, and to believe that light might be a shower of quanta or particles, but that it might be made of waves too, or perhaps a little of both. For no one to this day knows exactly what light is.

The attempt to understand the light was to lead many men along many difficult paths. And it was Isaac Newton who had started all this, for it was Isaac Newton who first broke the white light by putting a prism into a hole in a shutter, and looked at the rainbow colors on his wall—violet fading into indigo, to blue, green, yellow, orange, and red—and knew that the sunlight streaming through a prism was a mixture of all these.



17. Seen and Unseen

While Isaac Newton lived, his reputation had been great enough, but after he died it grew to gigantic proportions. Had he not explained the universe to the men of his time? Had he not told them why the earth moved round the sun, and why it did not go flying off into empty space? Had he not shown them how the white light could be broken, and produce at will the bar of myriad colors called the spectrum?

And Sir Isaac Newton had said that light was made of little flying corpuscles that streamed out from the lighted body. He had said that the idea of light waves was a mistaken one, and

that Christian Huygens, who had spoken of light waves, had been wrong.

Therefore the scientists for a hundred years after Newton's death believed in the little corpuscles of light, and no one troubled to experiment much more with light. The last word had been said about it. Why should they experiment further?

Of course, here and there in some laboratory, some physicist must have thought his findings did not check with Sir Isaac Newton's theory. But if there was such a man we know nothing of him. For who would set himself up to disagree, publicly at any rate, with that giant among scientific men?

But, at the beginning of the nineteenth century, Thomas Young, in England, dared to say that Sir Isaac Newton had been wrong, at least in regard to his theory of light corpuscles. He was laughed at and scorned for his presumption, but it did not matter to him greatly. He believed that he had found the truth, so he stated it. It was as simple as that.

Thomas Young had learned to be independent and to use his brain while he was still very young. He could read when he was only two, and had read the Bible through twice when he was four. These facts seem hard to believe, but they are told on good authority. At the age of six the boy could recite Oliver Goldsmith's *Deserted Village* from beginning to end. And if this does not seem a very useful thing for a boy of six to do, at least it is proof that he had a good memory, a quick mind.

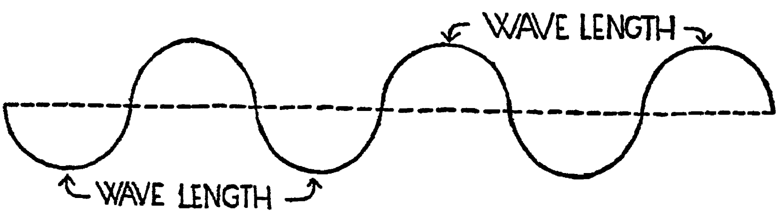
So as the years passed, Thomas Young began to read other books: the classics and books of mathematics. Not only did he read and study, but he must have thought about what he read, for when he was sixteen he stopped eating sugar because he disapproved of the slave trade.

He studied medicine when he was nineteen: studied at London, Edinburgh, Göttingen, and Cambridge—a good medical education, you might say. But though he pursued his medical studies so hard, it was physics or natural philosophy, as it was then called, that fascinated him most. In 1801 he was appointed professor of natural philosophy at the newly organized Royal Institution.

People have a way of trying to divide the sciences from one another, and of thinking of them separately. Yet in the creative mind they mingle together, for the truth is one. In Thomas Young's mind, physics and anatomy were one: the study of light and of the eye that sees the light could not be separated.

As time passed, his researches centered themselves more and more on the structure of the human eye. How did the eye work? What made men see?

He had not worked very long before he began to believe that Sir Isaac Newton's little streaming particles were impossible. It seemed to him much more probable that moving waves of light



struck the eye's retina and were recorded thence in the brain. The idea seemed so plain to him that after various experiments which seemed to him conclusive he wrote a paper on it, explaining how he thought light waves might work in relation to the eye. He read the paper to a group of scientists, and was immediately laughed to scorn.

It is easy to imagine their talk after the meeting was over. Waves? Waves of what? they must have said.

Thomas Young did not retract his statement. He was sure from his studies on the nature of the eye that he had been right. But he had many interests. He wanted to decipher Egyptian hieroglyphics; he was fascinated by the study of philology; he wanted to keep up his medical practice.

In 1801, however, he heard that certain Frenchmen, particularly one named Augustin Jean Fresnel, were making studies of theories of light, and he took up his old interest in the structure of the eye.

A paper which he read before the Royal Society and later published brought down a storm of disapproval upon him. Lord Brougham, commenting on his statements in the *Edinburgh Review,* said there was "nothing in them which deserves the name of experiment or discovery." He said Young's ideas were "absurd" and "illogical" and he wrote: "We wish to raise feeble voice against innovations that can have no other effect than to check the progress of science." And he ended his diatribe: "We now dismiss, for the present, the feeble lucubrations of this author, in which we have searched without success for some traces of learning, acuteness and ingenuity that might compensate his evident deficiency in the powers of solid thinking. . . ."

So spoke the leader of conservative scientific thought, the man who feared innovations, the man who thought that no scientist ought ever to be so bold as to disagree with Newton.

Thomas Young felt that Lord Brougham should be answered. He wrote a brilliant pamphlet, explaining his position, and he published it, and offered it for sale. Only one copy of the pamphlet was sold.

The whole matter might have dropped there, and people might have gone on believing that light consists of tiny streaming particles—perhaps for generations.

But Fresnel was experimenting with light in France. And in the course of his experiments he came to exactly the same conclusions that Thomas Young had reached. In 1816 he wrote to Young:

> But if anything could console me for not having the advantage of priority, it was for me to have met a savant who has enriched physics with so great a number of important discoveries, and has at the same time contributed greatly to strengthen my confidence in the theory that I have adopted.

He signed the letter with a flourish, and sent it by packet across the English Channel, to be delivered to the abused Dr. Young at his laboratory.

Dr. Young broke the seal, and read it quickly in the French that was as easy for him as his own English. When he had finished, he read it through again. So Fresnel and the French scientists agreed with him. He must have smiled as he thought of what Lord Brougham would say when he made this news public.

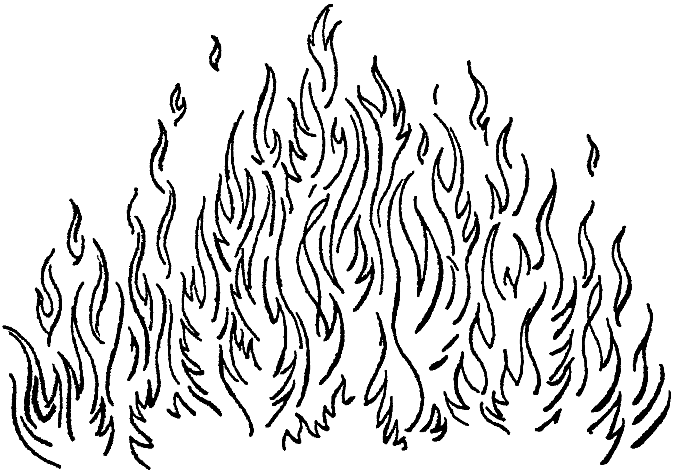
On the sixteenth of October, 1816, he dipped his quill into the ink, and, writing in a style more flourishing even than the one Fresnel had used, he too prepared a letter for the packet that was to cross the English Channel. He wrote:

> I return a thousand thanks, Monsieur, for the gift of your admirable memoir . . .

But the treatise which Young published in 1802 did more than corroborate Huygen's theory of waves of light. For Young

had presented the idea that these waves might be measured, from the tip of one wave to the tip of another. And he showed moreover that the difference in the various colors lay in the difference in their wave lengths. Red rays, for instance, had wave lengths that were nearly twice as long as violet waves. So he arranged the various colors in the spectrum according to their wave lengths. And since he had made studies of the human eye, it appeared to him probable that there might be colors that the eye could not see—wave lengths that it was impossible for the lens of the eye to comprehend. There were waves that could be seen, he thought, and waves that were unseen.

Soon many scientists were beginning to wonder what those other waves were like. Did heat occur in waves similar to the waves of light? They began to wonder about the relationship between heat and light. And as they had once argued and disagreed about what light was, now they were arguing about heat. What made things hot, after all? What made them cold?



18. The Fury and the Fire of Heat

"Whence is the fury and the fire of heat?" Francis Bacon had asked back in the sixteenth century. And he guessed at an answer to his question, writing in the formal style that was the fashion when he wrote his book, *Novum Organum:*

Heat is a motion of expansion, not uniformly of the body together, but in smaller parts of it; and at the same time checked, repelled and beaten back, so that the body acquires a motion alternate, perpetually quivering, striving and struggling . . .

"Heat is a motion," he had said. But it was only a guess, and Francis Bacon, for all he was continually saying that people ought to prove what they said by experiment, had no way of proving what heat was.

Democritus the Greek, who lived two thousand years before Bacon's time, had guessed much the same thing. He taught that

tiny particles flowed from some bodies with such speed that they penetrated solid matter. From them he thought the soul was born. The philosopher Plato agreed with that idea. Aristotle, too, thought that heat was made of tiny flying particles, although he had less confidence that the soul was made of them.

So for many centuries the notion persisted that heat was made of tiny flying particles: particles that flew so fast they could penetrate water, or a block of metal even. But all this time no one could prove it: no one really knew.

If you cannot prove your theory to be true, it is easy for someone else to say that another theory is equally credible. For more than two thousand years people held the idea that heat was a matter of tiny streaming particles: then they began to doubt it. For some unknown scientist had talked of "caloric." Caloric was a kind of fluid, he said. It was present in every earthly substance. Some substances had more of it, and they were warmer; some had less, and they were colder. You could squeeze caloric out of substances, or you could add it to them with flames. Colder bodies contracted because they had the caloric squeezed out of them; hot ones expanded because caloric had been added to them.

It was a fine theory, widely believed in the eighteenth century. But no one had ever proved that theory either: no one had ever seen caloric, and sometimes experiments with regard to it contradicted themselves. Benjamin Thompson, the American, refused to believe in caloric. He thought there must be some other explanation for why things were hot or cold. In the palace in Munich where he was making experiments with military explosives, he finally proved that the idea of caloric was nonsense. How he came to be experimenting in the service of

Charles Theodore, Elector of Bavaria, how that Elector appointed him colonel of cavalry and general aide-de-camp, and gave him a palace in Munich and a retinue of servants and a military staff to assist him—that is our story.

For Benjamin Thompson did not seem like a scientist at first, or indeed like the stuff that a colonel is made of. He was born in the middle of the eighteenth century in the town of Woburn, Massachusetts, two miles from the place where Benjamin Franklin was born. He wanted very much to have an education, but he was poor and he had to leave school when he was thirteen: he went to work as a clerk in a dry goods store. It is said that he was in the habit of walking eight miles from Woburn to Cambridge to attend classes at Harvard, and he tried hard to be a doctor. But training for the medical profession was too expensive for him, and he became a school teacher instead.

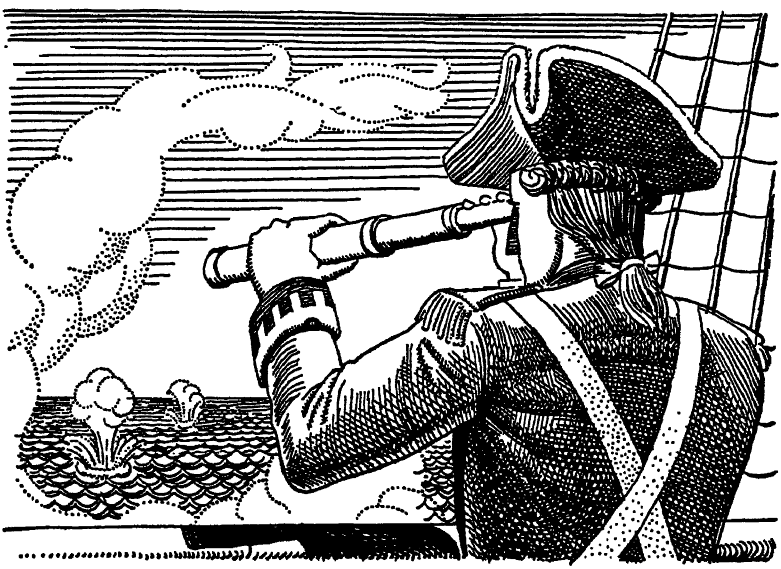
Then, the next thing we hear of him, he was getting married—and well married, by the world's standards. That was when he was nineteen. The bride was rich, the widow of a Colonel Rolfe; and Benjamin Thompson, who was a good-looking fellow, and a good talker, began to dress handsomely and to live well, and to have many influential friends. Then he looked down on the old neighbors who had known him in the days when he was a dry goods clerk.

The people that he looked down upon naturally disliked Benjamin Thompson; there was suspicion and gossip about him. It was 1774, and the tide of the Revolution was rising in America. Committees of Correspondence were being formed to seek out any who were disloyal to the patriot cause. Three times Benjamin Thompson was brought before these Committees and accused of being unfriendly to the cause of liberty.

Each time he denied the charge, but the last time he was thrown into jail for two weeks before his name was cleared. He was not a man of much patience. This was too much for him. He scorned the patriots, anyway: they were low-class rebels, he thought. That was why he made his way to Boston at last, and enlisted in the British Army under General Gage.

Benjamin Thompson did not take much part in the war against his countrymen. General Howe was driven from Boston by George Washington in March 1776 and Thompson was sent to England. He left his wife and young daughter behind him in America, and there is no record that he ever even wrote to them. His wife died a few years later.

In England young Thompson, who was now twenty-two, became colonel of the King's Dragoons. He was sent to America with a regiment the next year, but though he saw some action at Flushing, Long Island, he did little real fighting. Instead he



served the English king by making experiments with different kinds of bullets and powder. On one occasion he went on a three months' cruise with the British fleet, and persuaded the commander to shoot every kind of bullet and cannon ball as they cruised along.

When the Revolution was finally over, there was Thompson in the British Army, handsome in his uniform, eager to command. Before long, another opportunity seemed to offer itself, not in the British Army, but in the Austrian. For a war between the Austrians and the Turks was brewing, and the British king would give him permission for foreign service.

A war with the Turks seemed to be exactly the opportunity that young Thompson was waiting for. He set off for Eastern Europe, but unfortunately before he arrived at any battleground, peace was made; the war did not materialize. Benjamin Thompson must have been filled with disappointment. On his way back to England, however, he stopped at Munich, and there he was presented to the Elector of Bavaria.

Charles Theodore, Elector of Bavaria, was much impressed with Benjamin Thompson, his stories of his escapades in distant America, his experiments with explosives, his eagerness to fight the Turks. He offered him an appointment as colonel of Bavarian cavalry and general aide-de-camp. Thompson, excited at all this, hurried back to England to ask permission of George III to accept a commission in a foreign army, and this was granted and the order of knighthood given him to boot. He chose the title Count Rumford, taking the name Rumford from a little town in Massachusetts where he had lived.

Soon therefore Count Rumford was back in Munich, a palace at his command, servants to do his bidding, military aides at

his beck and call, and experiments in explosives going forward, by which he hoped to make the Elector of Bavaria respected and feared by all Europe.

Whatever may have been the shortcomings of Benjamin Thompson, laziness was not one of them. He worked extremely hard as the Elector's aide-de-camp for nearly fifteen years. And it was in Munich, working with explosives, shells, and cannon, that his great discovery as to the nature of heat was made.

It was a part of Benjamin Thompson's nature to love explosives: he made all sorts of tests to find out what kind of powder gave greatest speed to a bullet, what kind of metal would best withstand a given charge, exactly how a rifle should be bored. As he worked, Thompson became more and more interested in knowing exactly why there was heat when he lit a charge of powder. It did not seem to him that heat was a substance: the idea of caloric seemed to him most improbable.

He tried various experiments, filling one thin glass flask with alcohol and another with water, placing them in rooms with temperatures hot enough to make them boil or cool enough to make them freeze, weighing and comparing them. More and more it seemed to him that there was no such thing as caloric. But if heat was not caloric, what was it?

The old idea of moving particles came to him: heat is motion, he must have thought to himself. Who knows when the idea first came into his mind? In 1789, while he was directing work at the drilling of a cannon, he took the unfinished steel cannon and immersed it in a tank of water. Then he took a blunt steel drill, hitched a team of horses to it to make it rotate, boring its way into the metal of the cannon. The horses walked round and round for two hours and three quarters. The drill

bored deeper and deeper into the metal cannon. From time to time Thompson tested the temperature of the water. When the boring started the water was at 60 degrees Fahrenheit: at the end of an hour it was 107 degrees; in an hour and a half it was 142 degrees; "at the end of two hours and thirty minutes it actually boiled." Whence had the heat come that raised the temperature of the water from 60 degrees to the boiling point? When he began the experiment both water and metal had been the same temperature. Nothing had entered the water—nothing was altered. The only thing that was different was that there had been movement: the movement of the boring tool eating its way into the metal. Yet the water had boiled: heat had been generated by movement. Benjamin Thompson reported the experiment:

> It would be difficult to describe the surprise and astonishment expressed in the countenances of the bystanders on seeing so large a quantity of water heated, and actually made to boil, without any fire. . . . Yet I acknowledge fairly that it afforded me a degree of childish pleasure, which were I ambitious of the reputation of a *grave philosopher*, I ought most certainly rather to hide than to discover.

He tried again, using larger quantities of water, bigger cannon, boring faster. The result was the same. The water always boiled if he rotated the drill long enough: there seemed to be no end to the amount of heat he could make. He wrote that heat generated by friction appeared to be inexhaustible.

So Benjamin Thompson had established the fact that heat was not a separate fluid, but a form of energy resulting from the vibration of particles of matter. Other men were to make new discoveries—to find other sources of heat. But for the

present the old theory of caloric was vanquished, and Francis Bacon's question, "Whence is the fury and the fire of heat?" had been answered, at least in part.

With this beginning Thompson went on to more experiments, trying to find out exactly how much heat you may expect to generate from a given amount of energy, exactly how hard the horses had to pull in order to raise the temperature of a given amount of water a degree. He found that the amount of energy it took to raise 847 pounds one foot was exactly the amount it took to raise the temperature of a pound of water one degree.

It took pure mathematics to work out that relationship, intricate and difficult; it was work that required a brilliant mind and a perceptive imagination.

After Thompson had completed his experiments, he wrote a paper to be read before the Royal Society in 1798. The paper is written in the clear simple English on which he prided himself. For he had once said:

> Too much pains cannot be taken by those who write books to render their ideas clear, and their language concise and easy to understand. Hours spent by an author in saving minutes and even seconds to his readers, is time well spent.

But in spite of the clear manner of Thompson's descriptions of his experiments, there were a great many who refused to believe in what he said, and many who still believed in caloric. Only the passing of many years and the work of many other physicists finally banished the idea of this all-pervading substance. Practically every physicist today believes that what Thompson said was true, and that the waves of the heat may be measured as the rays of light are measured. They are a part of the spectrum, although they are not visible to the human eye.

It would be good to relate that after these experiments Thompson, with his brilliant mind, his genius for mathematics, and his capacity for hard work, went on to make more and more discoveries—for in his time there was much that lay ready and waiting to be discovered.

But instead of continuing with his scientific experiments he became head of the Bavarian Army, tried to improve the morale of the soldiers by raising their pay, organized schools so that the soldiers might be taught, got the government to build them better barracks, and set them to raising potatoes, draining swamps, and carrying on other public works in their free time.

Then he built a shelter for tramps and beggars in Munich, and had them bake their own bread and make uniforms and shoes for the soldiers. A great man Count Rumford was, in Munich. The Elector made him a count of the Holy Roman Empire in 1791, and a bronze statue was erected in his honor.

But though it is disappointing to know that he did not continue with his scientific experiments, he did one more thing for the cause of science that was important. This was the founding of the Royal Institution in London in 1799.

On the death of the Elector, Count Rumford went back to London, and there also he became interested in setting up workhouses and hospitals. He invented stoves that would heat these buildings properly, measured the amount of light that was necessary for lighting them, designed chimneys for them which did not smoke.

The English people did not like him much, but his inventions received much publicity. One poet wrote:

> Lo! every parlor, drawing room, I see,
> Boasts of thy stoves, and talks of naught but thee.

But the talk was not very charitable: people thought of him as a crank.

Nevertheless, his head was filled with plans for helping the Society for Improving the Condition and Adding to the Comforts of the Poor. It does not seem as if he did this work because he loved the poor in any way. He thought that they should be aided in order to make the state more efficient. He thought in fact, that all classes of people should be aided—and the best way to help them, he thought, was by ingenious mechanical inventions. That was why he began planning for the Royal Institution: an organization, not for the poor, but for all classes of people.

He thought that this Institution might be a sort of clearing house for inventions and discoveries of all kinds, and especially for discoveries in the fields of fuel, heating and lighting. He raised money from people of all classes, and opened rooms in London where laboratory work could be done. Young men were encouraged to study and work here, great men to give lectures on their discoveries. He planned a little museum of working models of various inventions.

The Royal Institution was chartered by the King in 1800, and Benjamin Thompson was the first director of it, running it in such a dictatorial way that he was thoroughly disliked. But after his resignation its work continued. The great chemist Humphry Davy worked there, and the gentle Michael Faraday conducted there his great experiments in electricity and magnetism. Many other scientists have followed these men: the work of the Royal Institution goes on in London to this day.

After Benjamin Thompson resigned as director of the Royal Institution he went to live in Paris, married a Frenchwoman,

the widow of Antoine Laurent Lavoisier, the great chemist who had been guillotined during the Reign of Terror. His wife was beautiful, popular, and gay, and she filled their house with the most fashionable people in Paris. But Thompson's interests were in their stoves, lamps, frying pans, and coffee pots: he insisted that each one of these should be of the most efficient and approved kind. He contradicted his wife in every smallest matter, and argued with their guests. So it was not long before the couple separated.

Now Benjamin Thompson, lonely, crochety, went to live by himself in the little village of Auteuil in France. And he began to make experiments to try to see whether a wide rim or a narrow rim was more efficient for a carriage wheel. People in Auteuil saw him driving around in a cart with big wide wheels, while theirs all had very narrow ones. They must have thought him very queer. Yet automobile wheels of today are all made with wide rims: of course they could not know that then.

But why spend more time on the life of an old man, and the opinions of an old man's neighbors? If it seems that Benjamin Thompson with his brilliant gifts might have done more for the world than he did, after all it may be said that he did two very great things: he established the fact that heat is a motion of tiny particles and not a substance called caloric; and he founded the Royal Institution, where other men made great discoveries. Thus he added another bit to men's understanding of the world they lived in.

19. *Quivering Space*

It was in 1672 that Isaac Newton let the sunshine through a prism, and broke the white light into its rainbow colors. In 1789 Count Rumford had bored his cannon under water and proved that heat and motion were related. In 1802, Robert Young published his treatise on light. In 1831 Michael Faraday had produced electricity from a magnet. These seemed to be isolated events, separated from each other, having no relation to one another. A very great mind was needed to guess that they were not separate and independent: that they were all evidence of a universal plan, a great design. James Clerk Maxwell's was the mind that proved they might all be brought together into a related whole.

It was in 1845 or thereabouts that the young Maxwell, then a boy of about fourteen, lay on a Scottish hillside not far from Edinburgh, where he had been born. He lay on his back, looking up at the light that streamed down from the sun, and touched the purple heather around him. Perhaps the gray skies of Scotland with their mists and their thick clouds, and their sudden golden flashes of sun, made the light seem all the more fascinating to him. He wrote in his autobiography many years later that he could remember lying there "looking at the sun, and wondering."

He was a solitary boy. His mother died when he was still quite young, and he spent a good deal of time alone in the country. His father put him to school in Edinburgh when he was ten—but he came away to the country on his holidays. And all this time, in school and out, he was thinking about light. What was it? What was the "go" of it?

The boy's interest was indeed so serious that his father decided to take him to the Royal Society in Edinburgh where scientific questions were discussed. The boy sat there, quiet and eager, and listened to the talk of the eminent Scottish scientists. But neither he nor they could get to the bottom of what they were talking about.

He was only fifteen when he published his first original piece of work, a mathematical paper on the theory of oval curves. Then in 1847, when Maxwell was sixteen, he heard at the Royal Society of a great scientist named William Nicol. No living man, it was said, knew so much about light as this man Nicol.

A sympathetic uncle succeeded in getting Maxwell an introduction to Nicol, and this was his final inspiration. From the day of this meeting he spent his life in the study of light.

He worked as a professor at the University of Edinburgh at first, then later at Aberdeen, and finally at King's College in London. At all these places he lectured to his college classes on physics and astronomy, and worked out mathematical equations and scientific formulas for his own satisfaction.

Not all his time was spent on science, of course. He loved to write verses, copying them neatly and carefully, and presenting them to his friends "with a sly chuckle," for no one enjoyed them more than he did himself.

He did not marry, but he had a number of aunts and cousins that he was very fond of, and he liked to mystify them by telling them that his scientific researches showed that blue and yellow did not make green, and trying to prove it by the use of light through prisms.

When he was teaching at King's College in London, he fixed himself a laboratory in the attic of the house where he lived, and spent much time in working with rays of light introduced through a prism into a big box eight feet long. The neighbors across the street reported that he spent hours together looking into a coffin: the suggestion was that he was a little mad. If he knew about their talk, he must have laughed.

Although he spent a good many hours looking into his black box, Maxwell was only partly an experimental physicist. He was a great student of other men's work, and a great mathematician. Working in his attic laboratory, studying the work of the scientists who had gone before him, he kept trying to understand this problem: how was the light carried to his eye, the sensation of warmth to his fingertip, the shock of the Leyden Jar to his hand? What were the light, the electricity, the magnetism?

Now Michael Faraday had been puzzled by these same

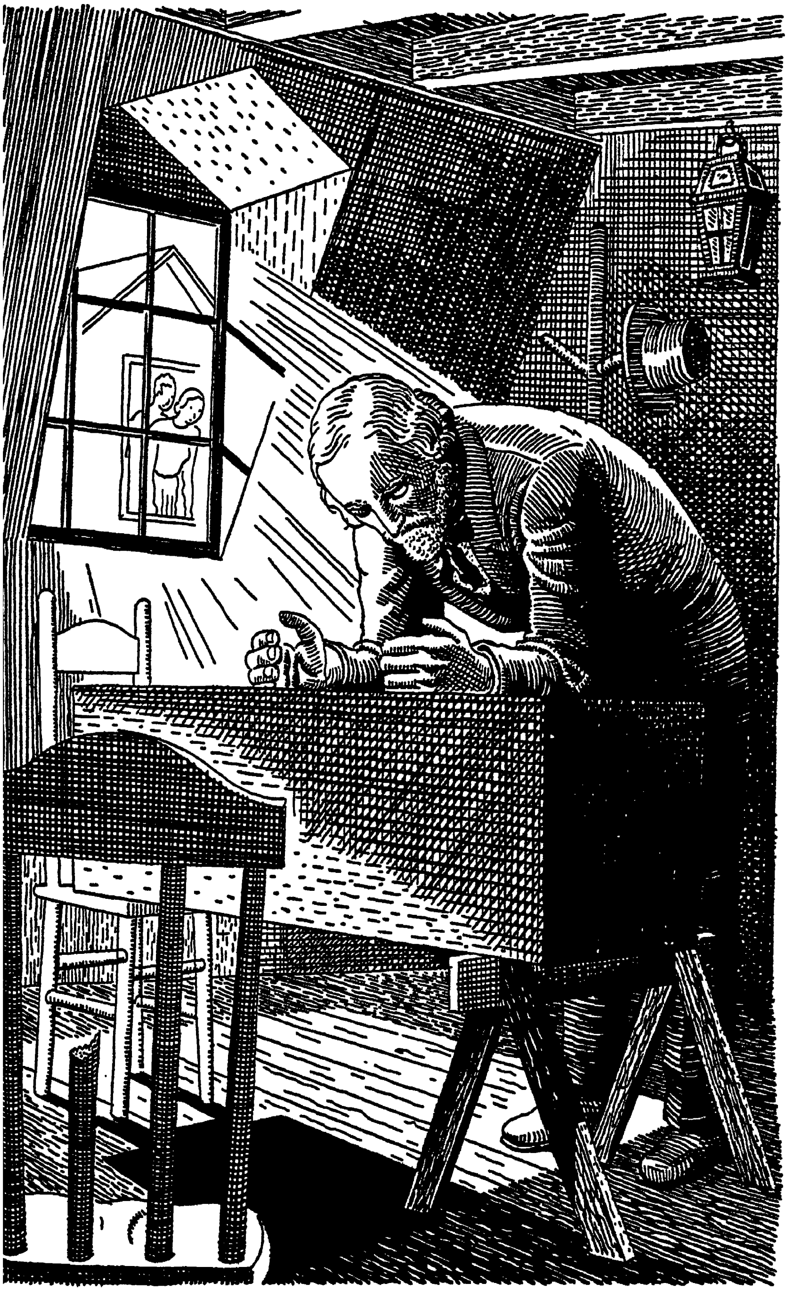
questions and although he was so brilliant at experiment, he had never been able to work out their solution. He knew that there was a field of magnetism around the electric current. He guessed that there was some relation between these and light and heat—but that was as far as he could go.

Maxwell was a great admirer of Michael Faraday and had studied his work closely. He had in fact prepared an article on Faraday's work for the ninth edition of the *Encyclopedia Britannica,* and this article is said to have been the greatest tribute to Faraday which has ever been made. So greatly did Maxwell admire Faraday's work that he said he studied his experiments with "something like religious reverence."

Maxwell himself was rather clumsy when it came to experimenting. But as he studied and thought on the question of light, it seemed to him that he could describe its movement mathematically, and that the influences of electricity, magnetism and heat were akin to it. Here then Maxwell had hit upon a truth that many scientists in the twentieth century were to corroborate. "Nature's great book is written in mathematical language," Galileo had said. And Sir James Jeans, writing at a later day, said that no one but a mathematician could hope "to unravel the fundamental nature of the universe."

So it was by pure mathematics that Maxwell worked out questions that had been experimentally impossible. The beauty of his results lay in the fact that the phenomena seemed to behave as his equations had described them.

What were these? Every electric current anywhere in the universe was associated with a magnetic field, Maxwell reasoned. There could be no electricity without magnetism: one



was impossible without the other. Electricity and magnetism traveled together in waves throughout all space—electromagnetic waves, he called them. These waves were not like ripples on the surface of a pool, they were perpendicular to the direction in which they moved as they radiated through space:))))))). They traveled with extraordinary speed—186,000 miles a second, the speed of light. And since the speed of the electromagnetic waves was identical with the speed of light, he assumed that light itself was the same as electricity and magnetism. Heat too, he reasoned, was of the same nature, another manifestation of the same energy traveling through space.

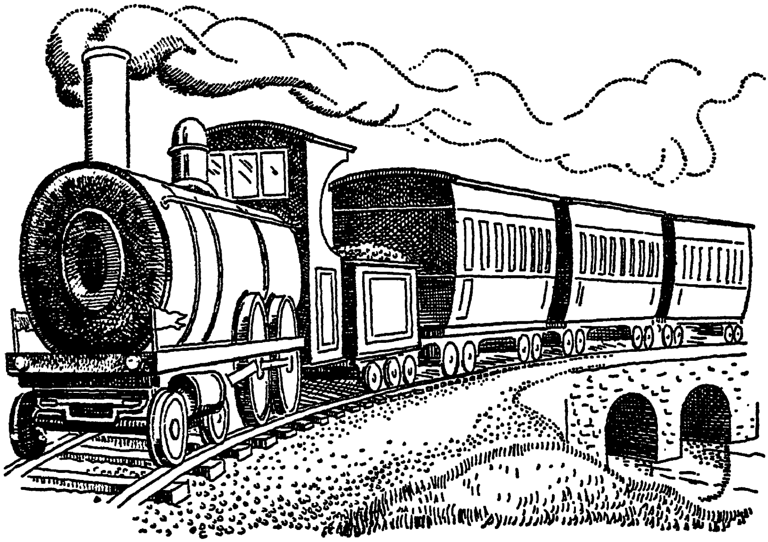
James Clerk Maxwell, sitting at his desk, working at his mathematical equations, imagined the spaces of the universe quivering with impulses whose existence no one had related before. Now the sunlight that shone across his paper, the lightning, the spark that his friction machine made, the impulse that pulled the compass toward the north—these were not separate phenomena. They were related to one another, a part of a great scheme. Scientists like Hertz, Röntgen, Marie Curie, and Becquerel were to find evidence of other radiations, varying in wave length and in penetrating powers, yet fitting into the great scheme. Some of these wave lengths were infinitesimally short like the cosmic rays, some, like the radio waves, were several miles in length. But James Clerk Maxwell could know nothing of these—they existed but no man had yet recognized them.

In 1873 Maxwell wrote a treatise on the "electrodynamic theory of light," and read it to the Royal Society where his father had taken him as a boy. Very few people were able to

understand the treatise after it was published. The scientist Henrich Hertz said of it:

Many a man has thrown himself with zeal into the study of Maxwell's treatise, and even when he has not stumbled upon unwonted mathematical difficulties, has nevertheless been compelled to abandon the hope of forming for himself an altogther consistent conception of Maxwell's ideas. I have fared no better myself.

Yet it was Hertz who was to prove by experiment that Maxwell's equations were correct. And Hertz was to discover that it was true, as Robert Young had prophesied, that there were quivering waves in space which human eyes could not see.



20. A Link in the Chain

It is not far from Hamburg to Berlin; people make the journey in a few hours now. But in the summer of 1878, when Heinrich Hertz took that journey, it was a long, slow trip. He looked out from his old-fashioned railway carriage at the meadows where the country folk were taking in their hay, at quiet rivers on whose banks boys sat fishing while women bent over their washing, beating the clothes with sticks, at little towns where peasants in their creaking carts were driving in to market places to sell their pigs and chickens and basketsfull of eggs. A long journey it was—plenty of time along the way for a youth of twenty to think of the things that he would do.

Heinrich Hertz was twenty then. He was taking that journey in the summer of 1878 because he was to enter the University at Berlin, and Berlin was a great center, even then. He was to learn to be a civil engineer, to build bridges and dams, to build highways and railroad lines, and all the other things a fast developing Germany would need.

Germany was a new nation in 1878. The Franco-Prussian War had ended in 1870, and, one by one, Baden, Bavaria, and Wurtemberg had joined the North German Union. On the 18th of January 1871, King William of Bavaria had been crowned Emperor of Germany. The crowning had been done with the indescribable enthusiasm of the German-speaking people.

Heinrich Hertz, traveling along through the rich German countryside, would learn to be a civil engineer. He would work and prosper, and be a credit to his family and to his Fatherland. This was the plan his father the Hamburg lawyer had made for him; this was what his mother, the daughter of a Lutheran clergyman, had assented to; this was what Heinrich Hertz himself had wanted.

Who knows what changed his plans? Who knows whether the change came into his mind slowly, or in a sudden flash? What thoughts were in his mind as he journeyed down through the green and beautiful German country that summer of 1878?

When he reached Berlin he did not enter the civil engineering school. Instead he registered in the school of physics, and began to work under the well-known professor Helmholtz.

An abrupt change this, in the young man's plans: a complete upsetting of his life's scheme. For as a civil engineer his future would have been secure; comfort and prosperity were practically assured to him. But as a theoretical scientist, what

was there for him? Who ever heard of a theoretical scientist making a fortune? What was he after? Why did he change?

But what, after all, is any scientist after? To search for understanding, maybe: to add a bit to the truth that has been revealed already, perhaps: to search—perhaps to find nothing.

And Heinrich Hertz had not been long in Berlin when he wrote to his parents: "I am now thoroughly happy, and could not wish for things better."

The special subjects on which Hertz was working were electricity and magnetism: and the great Helmholtz must have been an inspiring teacher. He recognized in Hertz a mind of promise, and believed him capable of original investigations.

That year the Academy of Science at Berlin had offered a prize for research in the electromagnetic waves that Maxwell had studied. Were there such waves? What was their nature? Could they be artificially created?

Were there such waves? Were there?

The young Heinrich Hertz refused to try the investigations at first. He felt he did not have the needed apparatus. Perhaps he was not quite sure of his own ability. For he once said, "The theory of electricity is so foreign to me."

But the next year Helmholtz brought the matter up again. He could get Hertz an instructorship at the University. That would open the laboratory to him; give him the use of all the apparatus he needed. He had a better grounding in the theory of electricity now.

Hertz wrote afterward about the original suggestion, "I reflected on the problem, but abandoned it for the time. In 1886 I took it up again, and by using apparatus that was available I produced electric waves. . . ."

"I produced electric waves," he said. The announcement was plain and simple: as plain as the laboratory where he was working; as simple and as exciting as the sunlight that touched his desk.

He had placed two coils of wire on his laboratory table, a break in each. He had induced an electric current from a Leyden Jar in one coil. A small spark leaped across the break in the coil; and a similar small spark was visible in the gap in the other coil. The electricity had traveled somehow across the space between them.

Now he worked with a stronger current, and perfected the receiving coil. He could send the electricity from one to the other across the intervening space at will. It was a common thing to send electricity along a wire at that time of course; and sparks had often been created at will. But to generate an impulse, and then to pick it up again at some distance—this was a new thing. It was a thing that would not have surprised James Clerk Maxwell in the least. He would have known that an electric-magnetic wave was there. Hertz knew it too. He had produced experimentally what Maxwell had worked out mathematically.

He poured the current into the first coil, and observed that the second coil received it, not steadily, but in spurts. He could measure the time between these spurts, or vibrations, as you might measure the waves that beat up on a shore, as you might measure the distance between the crest of one ocean wave and the crest of another.

Waves then: he was making waves. Waves of what? He did not know.

Outside the laboratory his life went on. He became a teacher

of experimental physics in Karlsruhe in 1885; he married Elizabeth Doll, the daughter of a professor, in 1886; he was made assistant to Helmholtz in 1888; then he lectured at the University in Kiel, and became professor of physics at the University of Bonn, a position that carried with it great prestige.

But those were only the externals of his life. What mattered to him, day after day—winter, spring, summer and fall—was his work with the coils in the laboratory, his making of those "electric waves." There were so many experiments he wanted to make with them. He tried reflecting them back from mirrors and metal surfaces: they reflected exactly as light waves reflected. He could send them straight through the wall of a house! He tried passing them through a prism: they were bent, as a light ray is bent. He tried measuring the wave lengths and found that they differed from light waves in that they were very long, some of them a fraction of a foot, and some as much as twenty miles. He measured the speed of the moving waves: it was 186,000 miles a second, the speed of light. They were the radio waves we know so well today.

The electric waves and the light waves behaved in the same way then—they were the same. Hertz went on to study heat. It too behaved in exactly the same way.

Heat, light, electricity—waves moving through space. Waves of what? He could not tell.

He was very modest about the work that he had done, claiming that he had only added a link to a long chain. "Such researches as I have made upon this subject," he said, "form but a link in a long chain. Lack of time compels me, against my will, to pass by the researches made by many other investigators; so that I am not able to show you in how many ways the path was

prepared for my experiment, and how near several investigators came to performing these experiments themselves."

In 1891 the Rumford Medal was presented to Hertz by the Royal Society in England, as a tribute to his distinguished work, and Sir Oliver Lodge, who was there when he received the medal, said that Hertz was "naturally and unexpectedly pleased" at the recognition given him by the English scientists. Lodge said the speech Hertz made "on the occasion of the bestowal (of the medal) will long be remembered by those who heard it for its simple-hearted enthusiasm and good feeling."

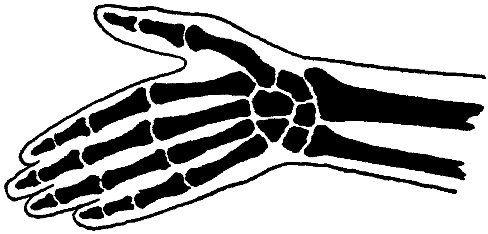
It was fortunate that this recognition of his work came to him in 1891, for the next year he contracted a chronic blood poisoning, and in 1894 he was dead. His hour of life and work had been very brief. He was only thirty-seven when he died.

Most people in Germany and in the rest of the world paid little attention to his dying. For he had been a quiet man, and it has always been true that great discoveries which are to influence the lives of many people are quietly made, with little fanfare. Heinrich Hertz had not been one to advertise himself and his work in any way. His mother said, "He was not really ambitious—only very eager."

Meanwhile in Italy the young Guglielmo Marconi read a paper which Hertz had written about the waves he had generated (Hertzian waves, they were beginning to be called), and he realized that they could be used for sending messages; and Lee De Forest, experimenting in a hall bedroom in New York, found out that the waves could be amplified and controlled by sending them through a vacuum tube with a metal grid in it, which he called a triode. Thirty years later the little radio receiving sets with their headphones had been replaced by much

bigger sets, and commercial radio was a commonplace everywhere. Now radio waves and their behavior were being studied in big industrial laboratories; and short-wave messages were sent across the wide oceans, to the very ends of the world.

Of course Heinrich Hertz could not have guessed all this. It probably would not have mattered to him very much if he had. He had been happy in his brief hour of life; he had added a link to the long chain.



21. Invisible Radiance

Sometimes discoveries are made by accident—not often, but occasionally. That was the way it happened with Wilhelm Conrad Röntgen, working in his laboratory in the University of Wurtzburg. He did not know exactly what he had found. Neither could he know how hospitals, and industries, and museums, would use the swift invisible rays that he produced, hunting for bullets or cancers in human bodies, discovering flaws in blocks of metal or cement, finding unexpected pictures under the surface of oil paintings; seeing and picturing what human eyes could not see.

Röntgen could have no idea how many men would find uses for his mysterious rays. But then, that was not his concern. After all, his business was to investigate: and that is what he did—working hard and patiently in his laboratory at the University of Wurtzburg. He made his discovery in the year 1895.

The little Bavarian town of Wurtzburg is built on both sides of the river Main some sixty miles from Frankfort. The two parts of the city on their opposite banks are joined together

by an ancient stone bridge which is adorned all along its six hundred and fifty feet by statues of the saints. But there are other bridges also at Wurtzburg, since the business of the city must go back and forth across them.

Around the city the hillsides are planted with vineyards: it is the boast of the citizens that there is no better wine in Germany than that which is made in Wurtzburg. And if you were there on a Sunday morning you would hear that the air was clamoring with bells, for the town is full of churches. There is not only the ancient Romanesque cathedral with its four square towers, but the Marienskapelle, and the Hangerstifts Church, and the Neumünster Church, and the Church of St. Burckhardt. Anyone could easily know that Wurtzburg is an important ecclesiastical city. And in fact the palace which was formerly the residence of the bishops and the grand dukes of Wurtzburg is still standing—or it was before the war.

But perhaps more important than the wine, or the churches of the city, was the University which Bishop Julius founded back in 1582. In a quiet laboratory of this University many years later, a Professor Röntgen made his experiments in physics.

Around the professor in his laboratory the paraphenalia of his work was arranged in orderly fashion. He had an electroscope, which was a large glass bell inside which were suspended two pith balls covered with metal and hung on a silken thread: when he touched the stopper of this jar with a rod charged with electricity, the pith balls moved apart or together according to whether the charge was positive or negative. Near this was a friction generator. There were many tubes of glass ranged on shelves, for Professor Röntgen was especially interested in the behavior of electricity when it was passed through gases,

or through a vacuum. Like many another scientist, he had made many experiments with Crookes tubes.

It was in fact in experimenting with a Crookes tube that Professor Röntgen made his accident—and his great discovery. For some reason that we do not know, he had covered a Crookes tube with a heavy dark cloth before he turned on the electric current. It happened that by accident a photographic plate coated with barium-platino-cyanide lay on the table near the tube. He had been working for some time with the gas-filled tube, covered with its dark cloth, when he noticed that the photographic plates on his table had begun to glow with a kind of soft fluorescence. He must have put down the tube and taken up the plate in some astonishment. Was it late afternoon when he first observed the phenomenon? Certainly the daylight in the room could not have been very strong. And here was this glowing thing, this soft light, like the light of a glowworm in the grass on a summer night. What was it that had caused the thing to glow? Certainly it was in some way connected with the electricity in the Crookes tube, for when the current was turned off the glowing stopped. Yet there was no connection between the plate and the tube. The impulse that caused the plate to glow must have traveled across the intervening space through the glass of the tube, through the dark cloth with which he covered it. Rays of some sort clearly, he must have said. Rays of what sort? They were not rays of light, for he had covered the tube with a heavy dark cloth. The rays had penetrated the cloth somehow.

Invisible to his eye, they had touched the photographic plate and made it glow. He tested them with his electroscope and found that they were electric. He tried bending them as if

they were light rays: they behaved something like light. He found that they could penetrate many substances like cloth, flesh, plaster of Paris. On the other hand they were stopped by some substances like metal and bone. Then if he held a photographic plate near his hand and let the rays penetrate it, the resulting picture showed the flesh as a mere shadow, but each bone was clearly marked.

What indeed were the rays? Professor Röntgen was a man of long scientific and mathematical training. He knew enough to be willing to acknowledge that he did not know. When he wished to solve an equation he was accustomed to signify the unknown quality by an X. He called his unknown rays "X rays."

It was not long before the news of this strange invisible radiance was brought to other laboratories, and scientific journals here and there published accounts of it. Since Professor Röntgen had no explanation for the phenomenon that he had discovered, many scientists doubted that he had found anything at all. In America, the *Scientific American* carried an article saying, "There have been received from Europe by cable very insufficient accounts of a discovery attributed to Professor Röntgen of Wurtzburg University. . . ."

And after describing Röntgen's work with the rays, the magazine went on to say, "It is yet too soon to indulge in the wild possibilities that have been suggested for the process. When the details reach us, the process will probably prove to be of scientific rather than practical interest."

But though many were skeptical, and reluctant to acknowledge the importance of the rays that had penetrated the dark cloth over the Crookes tube, gradually the scientists of many

countries knew the importance of what he had done. Then recognition came to Röntgen.

In 1900, five years after his discovery, he was given the Order of the Royal Crown by the Emperor of Germany, and in that same year he was made a baron by Prince Ludwig of Bavaria. In America, in 1900, Columbia University awarded him the Barnard Medal for the greatest discovery in science made in the five preceding years. And England, not to be outdone, gave him the Rumford Medal of the Royal Society. While in 1901 he was awarded the most prized of all scientific awards —the Nobel Prize in Physics.

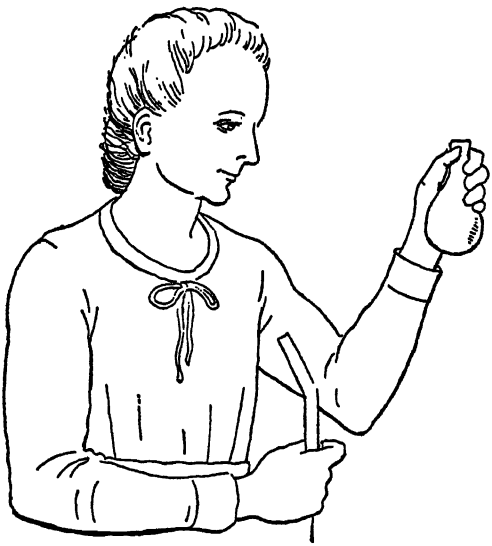
It is strange to think of Wilhelm Conrad Röntgen looking over all these medals and awards, prizing the tributes that his fellow scientists paid him for his accidental discovery certainly, yet not knowing exactly what that discovery was.

For it was not until 1912 that a German scientist named Max von Laue proved that the mysterious X rays were actually electromagnetic waves, but such short ones that it would take two hundred and fifty million of them to measure an inch.

Röntgen, sixty-seven years old at the time of this announcement, was working on in his German laboratory, his medals carefully put away. He must have heard of Laue's work with some excitement.

Meantime the news of Röntgen's discovery spread everywhere. Some people feared that they might somehow be used for the destruction of cities, and others thought their privacy and modesty would be invaded, since the rays could penetrate their clothes. A bill was introduced in the New Jersey legislature forbidding the use of X rays in opera glasses and a manufacturing firm advertised X-ray-proof underwear.

But in the laboratories where medical research was carried on, doctors were beginning to see that they could penetrate the outer body, and see in the shadowy X-ray photographs the broken bones or cancerous growths that they had only guessed at before. And once again the work of the pure scientist was proving of practical value to men.



22. *Discovery*

Little by little and bit by bit, the secrets of the great design were revealed. All through the rolling years they had been hidden: now in the course of a few centuries they were coming to light. Here and there a scientist working had revealed now one new fact and now another, and slowly men began to understand the world they lived in—but there was much still to be learned.

The seekers after understanding were widely scattered: no single country could claim them. They were French and German, English, Norwegian, Italian, American, Russian. For science knows no political boundaries. Some of the scientists were old men with years of patient work behind them: some were

very young with sudden fresh ideas that they were able to confirm. They were widely different in every way, but they were alike in their devotion to their work. And now, a new discoverer came, like the others, yet different from them. She was a woman: Marie Sklodovska, who later married and became Marie Curie. A slender gray-eyed Polish girl, she was to work for many years, until she became white-haired and old, and the world was to pay its gratitude to her for the work that she had done.

Marie Curie and her husband Pierre discovered new elements that no one knew existed before, elements that were different from anything that human eyes had ever seen, that helped men to understand in a new way the universe around them.

Of course the Curies did not walk out and find radium in the sense that Pizarro went to Peru to find gold. They charted their way in the first place on what other men had done, for this is the old eternal wisdom that scientists know. Isaac Newton once said, "If I have been farther than other men, it is because I have stood on the shoulders of giants," and Marie Curie would undoubtedly have said the same thing.

The man who gave Marie Curie her first inspiration was Henri Becquerel. Becquerel had done much experimentation in phosphorescence in Paris, and since his father and his grandfather before him had been physicists of some reputation, his findings were greatly respected in French scientific circles. And Becquerel had read of Röntgen's X rays, and wondered if they might be absorbed from the sunlight. He tried exposing salts of the element uranium to sunlight, then placing them on photographic plates. When he developed the plates, he found patterns on them, produced from the radiations of the uranium salt.

But there were certain substances, like phosphorous for instance, or like the stuff from which a glowworm is made, that seemed to be glowing all the time anyway, whether they were exposed to sunlight or not. How many of these were there, he wondered. Were there substances that gave off invisible rays like those that Röntgen found?

In an effort to find out whether there were such mysterious substances, Besquerel placed some uranium salts on a photographic plate, covered it with dark paper, and left it in a desk drawer unopened for two weeks. When he finally took it out and developed the plate, there was the image of the crystals as it had been before. A photographic plate could be developed only when light fell upon it. Yet no light had fallen here, for the plate had been covered with dark paper. Were there some other rays, not light rays, that the uranium salts were sending out?

He tried the experiment over again: the uranium salts, the photographic plate, the closed drawer. Again the pattern appeared when the plate was developed. What made it come? Was there something in the salt itself that gave out rays?

Marie Sklodovska Curie, the young Polish woman working with her husband in the laboratory in the School of Physics at the Sorbonne in Paris, heard of Becquerel's experiments: heard of them and pondered. Were there substances that were giving out rays all the time? What were those rays like? What happened to the substances from which the rays came? She thought about it more and more. She wanted to isolate some such substance, to find out more about it.

Many young people would have undertaken a more practical problem than this. They would have perfected some

device that could be sold, and tried to make a fortune. But Marie Curie did not concern herself with fortunes. She wanted to find out whether she could separate some substance which even in small measure was radioactive—which gave off rays of its own accord.

Marie Curie's enthusiasm was infectious. Her young husband, Pierre, a teacher in the School of Physics in Paris, would work with her. For Pierre and Marie were always to do their work together as long as Pierre Curie lived. They were very poor, but, if Marie's letters are to be trusted, very happy. When they made announcements of their discoveries they spoke as if they were one person. They generally said, "We found—" or "We discovered—"; that is, until Pierre was killed in a street accident in Paris. Then Marie went on working alone.

They began by bringing samples of minerals from the School of Physics, and testing each one for radioactivity. They found that those compounds containing uranium and thorium were the radioactive ones. However, their further study led them to believe that it was not the uranium and thorium but another substance, which gave out the rays. A new element, they believed it to be. They wrote, "If the existence of this new metal is confirmed, we proposed to call it *polonium*, from the name of the original country of one of us." That was in July, 1898. The announcement of the probable existence of polonium was the modest statement of their first success.

Then in December 1898 came another announcement, and this of a discovery of first rate importance. They had been working on an analysis of the ore pitchblende, and they wrote:

The various reasons we have just enumerated, lead us to believe that the new radioactive substance contains a new element to which

we propose to give the name RADIUM. The new radioactive substance certainly contains a very strong proportion of barium; in spite of that its radioactivity is considerable. The radioactivity of radium therefore must be enormous.

But if radium actually was in pitchblende, it must be separated, and weighed and measured, its reactions tested.

This was the task that Pierre and Marie Curie set themselves. They guessed that if radium was present in pitchblende it must be there in extremely minute quantities. It would be necessary to work a great deal of pitchblende ore to get a very little radium. Pitchblende was expensive. It was used in the manufacture of glass. But after the ore has been used in making glass, large quantities of slag could be bought for very little. Pierre and Marie Curie heard of a glass factory at St. Joachimsthal in Bohemia where pitchblende was used. They took what money they could get together to buy the slag and have it transported to Paris. The University permitted them to work in an old unheated shed not suitable for any other purpose. They set up big cauldrons and began to melt the ore, stirring it with iron rods.

I came to treat as many as twenty kilograms of matter at a time [Marie Curie wrote later] which had the effect of filling the shed with great jars full of precipitates and liquids. It was killing work to carry the receivers, to pour off the liquids and to stir, for hours at a stretch, the boiling matter in the smelting basin.

But again she wrote:

. . . And yet it was in this miserable shed that the best and happiest years of our life were spent, entirely consecrated to work. I

sometimes passed the whole day stirring a mass in ebullition with an iron rod nearly as big as myself. In the evening I was broken with fatigue.

The pitchblende ore in the big vats was olive-green at first. It bubbled and hissed, and sent off fumes, and Marie stirred it in her stained old smock with the wind blowing her hair. From the molten ore they extracted the uranium, together with cobalt, copper, silver, lead, and other substances. Now it was a thick brown mass, and this in turn was boiled day after day. The residue was filtered, dried, evaporated. Then it was ground and dried and crystallized and dissolved. With each step in the long process some unwanted matter was extracted, and the mass grew richer and richer in radium until tons of pitchblende had been reduced to a handful of silvery powder which they placed in a quartz bowl. This at last was heated until it was a boiling liquid and a film of crystals was skimmed from it. They were crystals of radium and barium.

It took twenty-three separate steps to separate the radium from the barium, but at last it was done. Finally they had what looked like a pinch of white table salt. It was the radium they had sought.

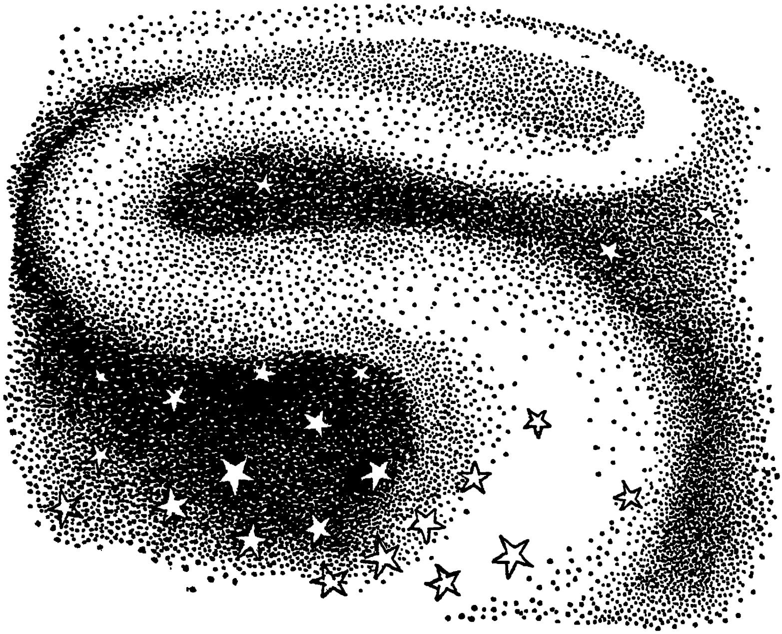
The precious particles of radium were placed in tiny glass receivers and put on tables and on shelves nailed to the walls of the shed. At night Pierre and Marie Curie stood silent, and watched it gleaming with a very faint light in the dark.

The rays from the new substance which the Curies had found were so powerful that they could pierce eight inches of lead, and the tubes had to be handled with extremest care for fear of dangerous burns. For the particles of radium were continually exploding, yet they seemed never to diminish in size. They

gave off great amounts of explosive energy with such force that any living substance that came in the path of the rays was destroyed. If a tube of radium was placed near a cancer, the emanations would kill the cells of the cancer. But great care had to be taken that the surrounding tissue was not injured at the same time.

At first radium was tremendously expensive because so much work had to go into its preparation and pitchblende was rather hard to get. But before long new deposits of the ore were unearthed, especially up near the Arctic Circle in Canada, and new and more efficient methods of preparing it were found.

Marie Curie must have been pleased to see her radium being prepared in larger quantities. She must have been pleased too that she was the first woman to receive the Nobel Prize and the only person who received that prize twice. She must have been glad too to think of all the hospitals where research in radium would make it possible to save so many human lives. Yet as the years passed, and she grew quieter, with whitened hair and a good black silk dress, her mind must often have gone back to the night, so many years ago, when she and Pierre, tired but triumphant, had stood in their bleak shed, and watched the faint gleam of their radium through the dark. For like discoverers standing on some strange peak and looking down into a beautiful new country, they were the first in all the world's history to behold radium, the stuff of which, in part at least, the suns and stars are made.



23. *Beyond the Milky Way*

Sir Arthur Eddington, the English scientist, once wrote, "A hundred thousand million stars make a galaxy, a hundred thousand million galaxies make a universe."

On one of the smaller of those hundred thousand million stars, in the first half of the twentieth century, men lived and worked with little thought of their place in the great celestial scheme. Science and the discoveries of science certainly affected the lives of these men even more than they knew. Because of Volta's work with electric currents they could send messages by telegraph and telephone; because of Michael Faraday's experiments with electricity and magnetism, the wheels of their factories could be driven with electric motors; because of the

experiments of Heinrich Hertz, radio and television were finally possible; because of men like Thomson, Rutherford, and Millikan, extraordinary electronic devices were made; because of scientists like Röntgen, Becquerel, and the Curies, new cures by the use of radiation were possible. There were countless other instances of how the dreams of the scientists had been embodied into practical instruments for man's help. To some it even appeared that the chief aim of science was its application to the life of men.

But there have always been some men who searched for an understanding of the world they lived in rather than for any practical application. These, the pure scientists, were willing to spend their efforts and even their lives to understand more clearly the laws that govern the universe. In the twentieth century with its wars, its luxury, its poverty, its industry, and its ingenuity, a few of these scientists worked on, often unheeded by the world around them.

A curious new problem faced them now, and they could have no rest until they solved it. As they worked it appeared to them that the solution of this problem would bring them an understanding of the deep secrets of the universe. These indeed were secrets worthy of all their labor and all their dreams.

The problem might have seemed insignificant and unimportant enough at first. Most people would not have guessed that there was any problem at all. It was simply this:

Early in the twentieth century a very delicate electroscope had been made to test the rays created by radioactive substances. Many experiments were made with electroscopes of this kind, and it was discovered that when they were taken into cellars or deep caves, they appeared to indicate that there

were certain rays present, even though there were no known radioactive substances there. No one knew why. There did not appear to be anything radioactive in the roof or in the walls. Was the earth giving out these strange unexpected rays?

Soon after the strange radiation was first detected in 1903, a great many men started to study these rays. They tested here and there to see if they could detect them and draw any conclusions on how the rays behaved. A French priest, apparently more enterprising than the others, carried his electroscope to the top of the Eiffel Tower in Paris. The radiations seemed much stronger there than on the earth.

Next the Swiss Aero Club, hearing of this experiment, decided to take a step further. They sent Albert Cockel up in a balloon to a height of three miles over the Alps. He took an electroscope with him, and he reported when he came down again, "There presumably was an increase of this strange radiation with altitude."

"An increase of this strange radiation . . ." What was it? What caused it? Where did it come from? It was something so small, so insignificant, that it could not be seen nor touched, yet because it was not understood, it tempted more and more men to work.

The search for an explanation of the rays had only just started, when the First World War brought almost all scientific research to a pause. But when the war was over, the search went on.

Now Robert Millikan, who had done such brilliant work with the atom, turned his attention to this new phenomenon. He carried his apparatus to the top of Pike's Peak, and compared its behavior at varying altitudes in other parts of the Rockies; he took it high into the Andes in Bolivia, to test whether

if he got out of sight of the Milky Way the radiations would be increased or reduced: he did not find that it made much difference. He lowered his electroscope to the bottom of Lake Gem in California, and found that the rays could penetrate two hundred and eighty feet of water: this he calculated was the same as penetrating twenty-five feet of solid lead.

The rays appeared to be very much like the rays which scientists had observed in studying radioactivity, but these rays were much shorter. They were in fact to be measured later and thought to be extraordinarily small. The distance from one to another was estimated to be five-trillionths of a centimeter (0.000,000,000,005 cm). This was ten times smaller than the smallest rays hitherto measured. Later it was determined that cosmic rays were not rays at all but particles.

Millikan made certain experiments with balloons in 1921. They confirmed his opinion that the rays came toward the earth from every direction from outer space. He gave them the name "cosmic rays."

More and more men were fascinated now by the cosmic rays. Three Russian scientists went up nearly thirteen miles in a balloon with their registering apparatus, and sent a triumphant message down to earth, "We have studied cosmic rays!" before the balloon exploded and they were lost.

And August Piccard, the slender scholarly Swiss professor, sealed himself with an assistant into the aluminum gondola of a balloon and succeeded in penetrating the windless stratosphere. The balloon drifted and it was thought that he too was lost, but he descended safely on an Alpine glacier at last with another bit of evidence. Then Admiral Byrd, on his expedition to Antarctica in 1935, took a scientist to measure the cosmic rays.

Deep in the salt mines of Stassfurt, high in the Rocky Mountains, from a station chopped in the ice on a shoulder of the Jungfrau, by day and by night, at the equator and near the poles, scientists set up apparatus and checked radiations. Their results were scattered and therefore inconclusive. What was needed apparently was a general organized plan: a way in which findings from every part of the earth could be assembled and compared.

But how could such a great organized effort be made? Never in all the history of science had work been done on such a vast scale. Perhaps that was why Arthur Holly Compton wanted to do it.

Compton had been absorbed in science from the time he was a school boy. He had been brought up in a college town, Wooster, Ohio, where his father was a professor of philosophy in the state college. His mother was a German—a member of the Mennonite sect. Both parents had taken the boy's education very seriously—had encouraged him when he wanted to photograph the stars, and helped him with other experiments.

Compton had planned at first to be an engineer, but his brother Karl Compton had talked to him of the beautiful laws of mathematics, and so it was that when he entered Princeton he decided to make these his study.

Compton left Princeton in 1916 with a Ph.D. *summa cum laude,* worked for a year in the Pittsburgh laboratory of the Westinghouse Company, and then went to England, where he worked at the Cavendish Laboratory under Sir J. J. Thomson and Ernest Rutherford.

It was about 1931 when he first became interested in cosmic rays. He had been led to their study through his interest in the

aurora borealis. The northern lights had held great fascination for him for some time. But he had been able to find no satisfactory explanation for the beautiful luminous banners that move across the northern skies. What was that radiance? Whence came the softly brilliant bands of light?

There had been various theories about them, but the one that seemed to him most plausible was that of the scientists Berkeland and Dauvillier. They held that the aurora borealis was caused by electrons shot out from the sun and reflected by the earth's magnetism to the upper stratosphere. They thought that the northern lights concentrated near the poles because the earth's magnetism was greatest there.

As he studied and considered the phenomenon of the aurora borealis, it appeared to Compton that there might be some similar explanation for the cosmic rays. Perhaps they too were electrons shot off from the sun, moving through space, reflected back from the earth. The man who understood them would understand not only the untold secrets of the sun and stars, but the workings of the distant universe as well.

Compton made some preliminary cosmic ray investigations; then he applied to the Carnegie Corporation of New York for the grant of a large sum of money and made a great plan for the detection of cosmic rays all the way round the globe.

He divided the world into eight regions, and selected a scientist and a group of assistants in each. The first region covered Greenland and Denmark; the second India, Ceylon, Java, and Tibet; the third was South Africa; the fourth Eritrea in northeast Africa; the fifth from Peru around the Cape of Good Hope and up to the United States; the sixth Spitzbergen and Switzerland; the seventh the Alaskan Peaks. Compton reserved the

eighth region for himself. With his wife and his fourteen-year-old son, he set out to make his study of it.

The Compton family had undertaken a vast project. They traveled fifty thousand miles around the world, stopping to climb the highest peaks with his instruments as they went from Hawaii to New Zealand, Australia, Panama; to Mexico City, to Peru and Switzerland; and to the Arctic North in Canada. The three of them climbed the mountains and sailed across the distant seas, until at last the globe was circled, and they were ready to compare the data they had collected with information that had been assembled from the seven other areas of the world.

Gradually the findings of all these searchers began to take on a pattern; they were sufficient to permit Compton to draw some conclusions. All the collected data seemed to confirm the fact that cosmic rays everywhere increase in intensity at higher altitudes, and therefore come to the earth from outer space. The strength of the rays moreover varied according to their position on the earth: those in the polar regions were as much as twenty per cent more intense than those at the equator. And they were stronger in the daylight than in the dark. They were 1.5 per cent stronger, to be exact.

But what were they made of? Tiny particles of matter, for the most part, Compton thought, although they might perhaps have several constituents. Sir Isaac Newton and Thomas Young, who had puzzled so much about whether light was made of waves or of particles, would have been interested in this statement.

But Compton and the other scientists who were investigating cosmic rays had only made a beginning of the study. The work

is still going forward. Electroscopes are being sent to the Orient and to the Antipodes, and plans are being made for permanent observation posts on high and lonely peaks. New flights into the stratosphere are being planned, and rockets are being developed which can carry apparatus far up to the spaces that lie between the stars.

For with all this work going forward, we really know but little of these radiations or of any others.

What are the cosmic rays? How are they made? "A hundred thousand million stars make a galaxy," Sir Arthur Eddington said, "a hundred thousand million galaxies make a universe."

And in the universe great forces are at work on which we can but dimly speculate. Some scientists think that the material in the sun and in the stars is disintegrating. As it crumbles away and gradually disappears, through the slow ages, energy is liberated in the form of cosmic rays which travel with the speed of light until they are finally reflected on the earth.

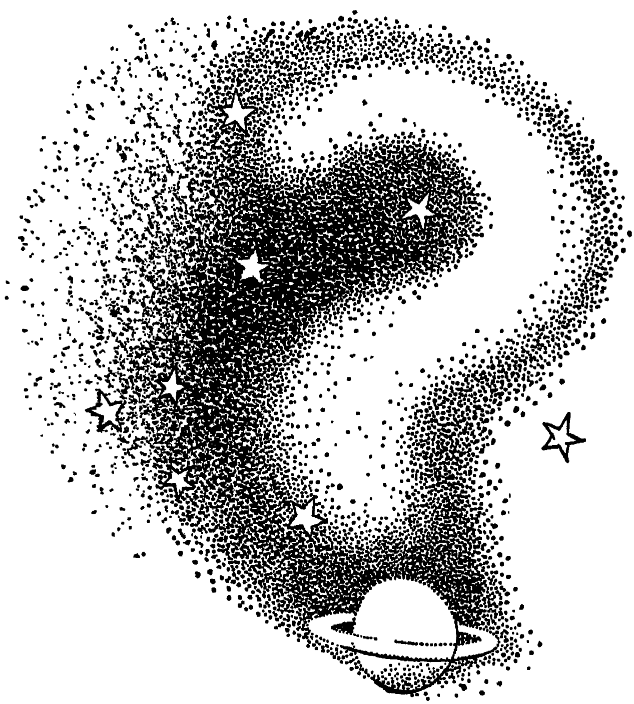
But others believe that the cosmic rays are not the sign of disintegration, but that they are born when lighter elements like hydrogen are welded together in the stars or in the outer spaces beyond the stars, and form themselves into new elements. The cosmic rays then would be the result of creation far off in time and space.

There is a third group of scientists who believe that cosmic rays are not solely the result of either creation or annihilation. They consider them a kind of cosmic pulse beat, as matter changes itself into energy in the distant spaces of the universe, and energy turns back to matter.

What is the truth of it? Who knows? The man who knew would understand the ultimate secret of the universe, the mind

of God, as Sir James Jeans has called it. The mind of God is still a mystery—unsolved, although the physicists by their work have come a long way.

It seems as if the hardest part of the physicists' work lies still before them. That work began when Peter Peregrinus studied the stone that was "alive," and William Gilbert observed the strange attractions of the amber that he rubbed. But now the physicists must seek to understand the movements of the atoms of which the stars are made. Their laboratory now extends out into space, beyond the Milky Way.



Suggestions for Further Reading

Curie, Eve. *Madame Curie, A Biography*. New York: Doubleday, 1937
The simple and very human story of Madame Curie's work, written by her daughter.

Eddington, Sir Arthur. *The Nature of the Physical World*. New York: Macmillan, 1933
The great British scientist explains the universe in terms of the theory of relativity and the quantum theory, and shows what he believes a universe so conceived means to men and to their religion.

Frank, Philipp. *Einstein, His Life and Times*. New York: Knopf, 1947
An interesting and well-written biography of Einstein, showing his work not only as a scientist but as a great humanitarian.

Gamow, George. *The Birth and Death of the Sun; Stellar Evolution and Subatomic Energy*. New York: Viking, 1940
George Gamow holds "the sun is simply the best working and most ingenious type of nuclear machine." This book tells you why he thinks so.

Hecht, Selig. *Explaining the Atom*. New York: Viking, 1947
This book explains the structure of the atom and shows how through its study "a wonderful tool has been made available and vast stores of energy have been opened that can keep us going even after coal and oil reserves have been exhausted."

Jaffe, Bernard. *Men of Science in America*. New York: Simon and Schuster, 1930
Among American scientists with whom this volume deals are Benjamin Franklin, Benjamin Thompson, Joseph Henry, and Ernest O. Lawrence. The lives of these men are extremely well told and interesting.

Jaffe, Bernard. *Outposts of Science, A Journey to the Workshops of our Leading Men of Research.* New York: Simon and Schuster, 1935
Here are clear accounts of recent researches into matter, radiation, and astrophysics.

Leonard, J. *Loki, The Life of Steinmetz.* New York: Doubleday, 1929
This biography gives an account not only of Steinmetz and his work but of the early days of the General Electric Laboratories in Schenectady.

Jeans, Sir James. *The Mysterious Universe.* New York: Macmillan, 1931
Sir James Jeans says, "The new teachings of astronomy and physical science are destined to produce an immense change on our outlook on the universe as a whole and on our views as to the significance of human life." This book explains what he thinks that change will be.

Jeans, Sir James. *The Growth of Physical Science.* New York: Macmillan, 1948
Beginning with the Egyptians and their measurements of the pyramids, and coming down through the Greeks and Alexandrians to the birth and development of modern science, Jeans traces the threads of mathematics, mechanics, astronomy, and physics, to the very latest theories of the present day. The book makes rather hard reading, but it will be interesting to mature students.

Smyth, Henry DeWolf. *Atomic Energy for Military Purposes.* Princeton: Princeton University Press, 1945
This is the official report of the development of the atomic bomb under the direction of the United States Government. It tells the whole story from 1939 when the possibility of nuclear fission was first announced, to the testing of the atom bomb in 1945.

Still, Alfred. *Soul of Amber, The Background of Electrical Science.* New York: Farrar and Rinehart, 1944
A very readable and simple account of the history of electricity.

Thompson, Silvanus P. *Michael Faraday, His Life and Work.* New York: Macmillan, 1898
Although this biography was written fifty years ago, nothing better has appeared on the life of this great man.

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